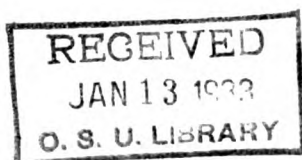


DEPARTMENT OF COMMERCE
UNITED STATES BUREAU OF MINES
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INFORMATION CIRCULAR

PROSPECTING AND EXPLORATION
FOR SAND AND GRAVEL



BY

J. R. THOENEN

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

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INTRODUCTION

The objective of this circular is threefold: First, to describe briefly the various modes of occurrence of sand and gravel. Second, to emphasize the need for adequate prospecting and exploration prior to the expenditure of funds for development and plant construction. Third, to describe various methods of prospecting and exploration and their application to the several modes of occurrence of sand and gravel.

Sand and gravel may be found in nearly every county or township in the United States. Commercial deposits, however, are by no means so widespread.

The introduction of concrete and the consequent impetus given to consumption of gravel and sand aggregates has seriously depleted deposits in some congested areas. Increasing restrictions in the specification requirements for marketing sands and gravels have further narrowed the economic areas.

On the other hand, the combination of increasing transportation costs and decreasing selling prices has forced the decentralization of gravel production. As a result smaller, intermittently operated, and widely scattered portable or semiportable unit plants have been encroaching on the territory formerly supplied from centrally located pits with large treatment plants.

Generally speaking, the small portable plant can not produce any great variety of materials to as exacting specifications nor as economically as the large permanent plant.

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used:

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2 - Senior mining engineer, U. S. Bureau of Mines.

The imperative and insistent demand for constantly decreasing construction costs has focused attention on ways of eliminating or reducing transportation costs which make up such a large item in the consumers' bill. Substitution of autotruck haulage for railway transportation has been the solution in some localities. Improved mechanical equipment of the portable or semiportable type with which materials could be exploited nearer the point of consumption and thus effect a reduction in the cost of freight has been the answer in other localities.

To meet this demand manufacturers have made great improvements in portable equipment, and now many of the more modern wayside plants can compete on nearly equal terms for specification material with their larger adversaries within certain specification limits. This does not mean that the small plant is displacing the large plant. A portable plant is ordinarily set up to produce material to meet the specifications for a single construction project. By careful study of the deposit the plant can be designed to produce the desired material economically for that particular job and location. Upon completion the plant must be moved and redesigned for its next set-up.

The large plant, on the other hand, is designed to produce a variety of materials to meet different sets of specifications. Therefore, although it can meet consumers' demands for quantity and quality over a wide range of divergent requirements, it is handicapped by distance and freight charges in supplying certain customers situated closer to local deposits on which specially designed small plants can be established.

This decentralization of production has accentuated the need for careful prospecting and exploration. The operator of a large established plant has, over a period of years, accumulated an extensive knowledge of the physical characteristics and limits of his deposit. New deposits, not previously worked, present a problem in ascertaining their suitability for the particular project they are called on to supply. Without careful preliminary search and testing there is grave danger of expensive development and attempted exploitation of deposits which are totally unfitted for the market they were hoped to supply.

The sand and gravel operator is principally interested in the mode of occurrence of the material. The prospector, on the other hand, is interested in the mode of formation of the deposits and the origin of their constituents. Sand and gravel deposits are formed from widely divergent materials in various ways, and require vastly different methods of exploitation. Therefore any intelligent attempt at opening new property should be preceded by the most carefully planned exploration as a foundation for proper development and plant design. This requires a knowledge of the origin of the materials that make up the deposit, their method of collection and deposition, and the various ways of testing virgin areas, in addition to a thorough knowledge of the proper type of production equipment best suited to local conditions of deposit and market.

PRIMARY FORMATION OF ROCKS

Rocks as originally formed are of igneous (molten) or sedimentary (deposited) sources. Examples of igneous rocks are trap, granite, lava, etc. Examples of sedimentary rocks are limestone, sandstone, shale, etc. Sand and gravel are the disintegration products of both igneous and sedimentary rocks.

The first rock formations to appear on the earth's crust were eruptive or igneous. These solidified from molten magmas by cooling. As they solidified or froze they were at once subjected to the disintegrating effect of the atmosphere and recurrent changes in temperature.

Frequent and wide variations in temperature with their expansive and contractive effects may themselves break up rock masses. It must be remembered that all igneous rocks are com-

posed of various assortments of minerals. Heat and cold affect different minerals in different degrees. Therefore alternate heat and cold will cause internal stresses within the rock mass until finally planes of weakness develop and fractures occur along them. These original fractures may be minute in size but sufficient to allow the entrance of air and its burden of moisture. As the moisture-laden air penetrates these fractures or cracks, the attendant decreases in temperature condenses the moisture and leaves it behind. This illustrates one way in which moisture may penetrate a rock mass.

Moisture may also penetrate a rock mass through capillary action along the crystal faces of the constituent minerals.

A third method is by direct solution. Igneous rocks are ordinarily considered insoluble. However, there are practically no known minerals or rocks that will not dissolve in water under proper conditions of temperature, pressure, and time. Certain mineral constituents of rock masses react more readily to solution than others; hence, their presence offers points of differential attack by direct solution.

Irrespective of the method of penetration, the presence of water within a rock mass is a most potent agent of its destruction and disintegration. Speaking broadly, water is a better solvent or penetrating agent the higher its temperature. In areas where atmospheric temperature changes range from above to below freezing, the action of frost greatly accelerates the disruptive effect of moisture. As water freezes it expands, and when confined as in rock masses it builds up pressures to 150 pounds per square inch.³ This internal force is capable of disrupting the strongest rocks.

Some minerals take up or absorb water by hydration. By so doing they increase their volume and thus set up internal stresses similar to frost action. Other minerals oxidize from contact with the atmosphere and thereby their cementing and cohesive strength is weakened.

In these ways the original igneous rocks were gradually broken down to masses ranging in size from fine particles to huge boulders.

Another process of disintegration was the movement of these fragments from their residual position by stream and gravity action. As the streams pushed and rolled them the constant abrasion between individual pieces further reduced their size by detaching coarse or fine particles. Thus were formed gravel, sand, and silt, which were carried by wind or water and deposited in flood plains, and in the beds of streams, lakes, or oceans. This sand and silt may remain unconsolidated, or under the pressure of the sea and by the aid of dissolved reagents in the water may be consolidated into the second class, or sedimentary rocks.

The preceding description of the elementary principles of early geology presents the essential differences in the formation of igneous and sedimentary rocks.

Further shrinkage of the earth's crust due to cooling set up enormous stresses within the earth which caused displacement of the surface and the formation of mountain ranges or lesser uplifts of land masses. (Geologists are not in complete accord as to the details of these mountain-building forces.) This movement brought portions of the sea bottom above the water line, while at other points land masses sank below the sea. As a result, sedimentary rocks were elevated to positions from which they in turn were subjected to erosion by air and water. Conversely, igneous rocks were submerged to new sea bottoms and thus became the floor on which new formations of sedimentaries were deposited.

At times this shrinkage of the crust caused surface movement beyond its tensile strength. This resulted in breaks in the crust and the relief of internal pressure by extrusion of molten masses. Volcanic action is typical of this phenomenon. These eruptive or extrusive

3 - Stone, R. W., *Molding Sands of Pennsylvania*: Topographic and Geologic Survey of Pennsylvania, Bull. M 11, 1928.

formations covered older igneous or sedimentary rocks alike.

Visualizing a continuance of these several formational phenomena over millions of years and under temperature changes unknown to-day presents a picture of the ways in which the present surface became such a mixture of mineralogic, geologic, and structural complexities.

OCCURRENCE OF SAND AND GRAVEL

To be of commercial value sand and gravel deposits must contain sufficient tonnage to warrant the erection of a recovery or treatment plant. Such deposits have been formed in a number of ways. Some fine sands have been picked up, transported, and deposited by wind. These are found in deserts and on some lake or ocean beaches. As a rule, they are too fine for commercial purposes. Except for these eolian deposits, all sand and gravel have been collected and concentrated by water or ice.

Roughly, commercial sand and gravel deposits may be classified in four groups with reference to their method of formation, as follows:

1. Residual.
2. Fluvial.
3. Marine and lake.
4. Glacial.

Residual Deposits

Sand and gravel found in situ or at the same location as the parent rock and resulting from its weathering or atmospheric disintegration are called residual deposits.

They are commonly unstratified, heterogeneous mixtures of boulders, pebbles, sand, and clay. They may contain much soft or inferior material commonly called rotten stone. This soft material, although originally dense and hard, has through prolonged weathering become porous and weak in structure.

Such materials have not been subjected to the abrasive action of transportation by water or ice. The particles may be angular or rounded. In either case, the surfaces will be rough and granular as distinguished from the smooth surface of water-worn material.

Residual deposits commonly form a rock mantle over the parent formation. They are ordinarily so intermixed with clay as to be of little commercial importance. In some localities, however, when other forms of deposit are absent residual deposits have been and are being utilized.

Fluvial Deposits

Sand and gravel picked up and transported by stream action form fluvial deposits.

Such deposits may be more or less stratified and they frequently show rough sorting in sizes. Coarse sand and gravel may be interspersed with lenses of fine sand or clay. Deposits have their long axis parallel to the direction of the stream flow. The beds usually vary greatly in thickness and may be complex in composition.

Particles are as a rule poorly sorted and may be angular or rounded. When rounded the surfaces are typically smooth. Whether they are angular or rounded depends on the hardness of the rock and the distance the material has been transported. The less resistant rocks such as limestone, shale, or sandstone will form rounded pebbles in comparatively short distances while the harder materials such as flint and quartz may travel a considerable distance before losing their angularity.

Fluvial deposits usually overlie an eroded rock floor, but may be found above finer materials. Since the transporting medium is water they are found in a variety of structural forms. Present rivers are constantly constructing, tearing down, and reworking bars within their banks. Similar deposits have resulted from similar action by ancient rivers which have long since cut down to lower levels, been diverted to other courses or have dried up. During periods of high water rivers leave their banks and extend over wide flood plains leaving considerable material behind as they recede. At their mouths they deposit their loads in delta formations. Swift mountain streams emerging from narrow canyons or gorges onto broad flat plains deposit their material in alluvial cones. Old streams in wide valleys leave terraces behind as they cut their way down to lower levels. These are all typical fluvial deposits.

Marine and Lake Deposits

As the term implies, marine and lake deposits are formed in ocean or lake beds or beaches. Subsequent to their deposition they have been uplifted from the sea to form continental land surfaces or the lakes have been drained, or dried up, leaving their beds exposed.

In structure these deposits frequently show well-sorted materials with coarse and fine particles segregated. The various segregations usually have their long axes parallel to the shore line. Such deposits are rarely over 100 feet thick.

Individual particles of marine sands range from angular to well rounded, while pebbles are usually well rounded and smooth.

Marine deposits consist ordinarily of hard, tough materials received from streams and reworked by wave, tidal, and marine-current action. Occasionally pebbles of limestone of organic origin, such as corals, may be present. Due to the erosion of shore lines and subsequent continental uplift, deposits of marine sand and gravel are frequently found on the landward side above consolidated rocks of igneous or sedimentary origin. Subsequent erosion by streams may leave marine sands and gravel at the tops or on the slopes of interstream areas or hills. Erosion by the sea or lake may leave terraces parallel to the shore line.

Sand and gravel collected in lake beds present structures similar to marine deposits except that the materials are usually not so well sorted and cleaned. They are also less apt to be well rounded.

Glacial Deposits

Glacial deposits of sand and gravel are found along the Canadian border in the western States, in the north-central or Great Lakes area, and in the northeastern portion of the United States. They are confined to that area which was covered by the great ice sheets that crept down from Canada and to the mountains of the West where isolated local glaciers occurred.

Structurally the materials are largely unstratified heterogeneous accumulations of boulders, gravel, sand, and clay. These accumulations are left as ridges or irregular deposits termed "moraines." As the ice from local mountain glaciers proceeds down the valley, talus from the mountain sides falls upon it and is carried on. The glacier by pressure and abrasion also picks up and carries material along in its base. When the melting rate at the terminus equals the rate of advance of the ice, the front remains stationary. The accumulated debris is then deposited in great terminal or marginal moraines marking the temporary edge of the ice. As the ice retreats, the debris is left as lateral moraines along the valley sides and ground moraines on the valley floor. Terminal moraines thus have their long axes parallel to the ice front while lateral and ground moraines usually have their long dimensions in the direction of ice flow.

Recessional moraines are terminal moraines marking points of pause in the retreat of the ice front. Later advance of the ice may totally remove these deposits or cut through them and on subsequent retreat leave other material as terraced lateral moraines.

The great ice sheets originating about Hudson Bay where igneous rocks predominate^{ccs} and sedimentary rocks are comparatively scarce brought down huge quantities of boulders, sand, and gravel of igneous origin. They also scoured out valleys in sedimentary rocks en route and carried along vast quantities of this material. Therefore glacial materials are composed of a mixture of hard and soft rocks. Most of this material was carried at the base of the advancing ice where it was subjected to terrific pressure and abrasion and also acted as an abrasive on the formations passed over by the ice. There is not much stratification or sorting in moraine construction itself, but in places much material was rehandled by escaping melt water and deposited as stratified outwash in valleys leading away from the moraines. This action is described under fluvioglacial deposits. Individual particles are seldom well rounded but are usually subangular and the larger pieces frequently show striated surfaces caused by abrasion against underlying rock formations while held in the base of the moving ice. Fresh feldspar and other decomposable minerals may be present where the deposits have not been subsequently subjected to excessive weathering. Such materials have been transported in the mass of the ice where they were not subjected to excessive abrasion.

The glacial data on Fig. 1 is from an unpublished map compiled by Wm. C. Alden of the U. S. Geological Survey and shows the principal terminations of the various advances of the ice sheets.

Although the preceding methods of formation are quite different in their manner of operation and produce deposits quite dissimilar in character, there are few deposits of sand and gravel which do not present evidence of more than one formational agency.

As examples, marine deposits when elevated to continental land surfaces are subjected to erosion. Marine gravels are thus picked up, carried off, and redeposited in fluvial deposits. Melting glaciers form the sources of streams and rivers which pick up, transport, and redeposit moraine material as fluvial deposits. Likewise residual materials may be picked up by a change in the course of a stream or by an advancing glacier and redeposited as a fluvial, glacial, or even marine deposit. Consequently present sand and gravel deposits may contain materials having complex histories.

GEOGRAPHIC DISTRIBUTION OF DEPOSITS

In order to apply the preceding principles of geology to present-day conditions in the United States the sand and gravel prospector must have some knowledge of the physiography and topography of the country. A detailed description of the multiplicity of natural phenomena which brought the formation and development of continental United States to its present state is entirely without the field of this paper. For such data the reader is referred to the many published treatises on the geologic history of our country to be found in public libraries. For more detailed study he will find much of value in the reports of the U. S. Geological Survey and the various State geological surveys.

In brief, the United States may be divided physiographically into four general areas, namely:

1. The interior plains.
2. The plateau and mountain areas.
3. The Atlantic and Gulf coastal plain.
4. The glaciated area.

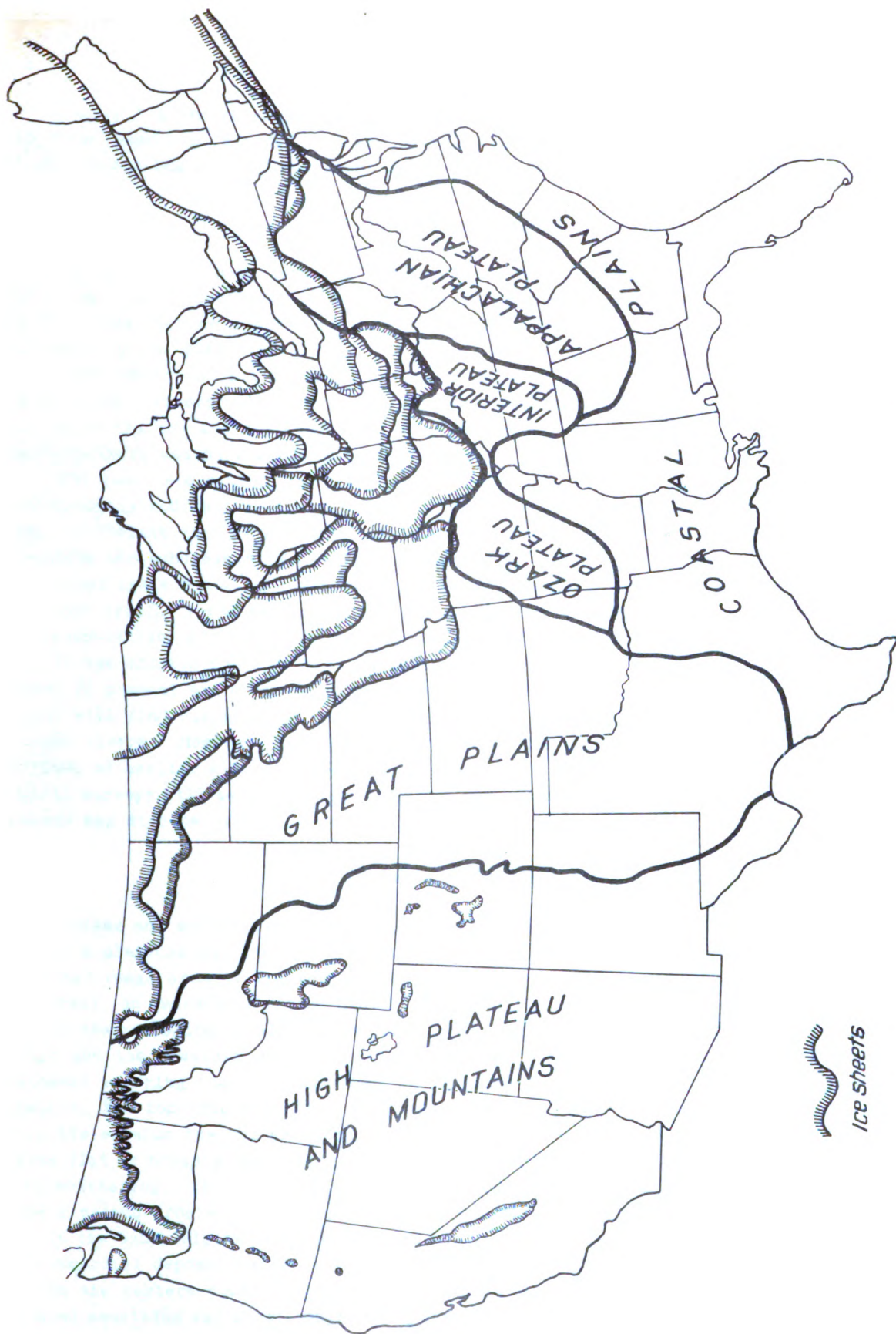


Figure 1.- Physical divisions of the United States

Figure 1 shows roughly the sections covered by these divisions. For further subdivisions the reader is referred to a map compiled by N. M. Fenneman entitled "Physical Divisions of the United States" and published by the U. S. Geological Survey in 1930.

Interior Plains

The interior plains comprise the drainage area of the great Mississippi River system, extending from Pennsylvania on the east to the Rocky Mountains on the west and from the Canadian border to the coastal plain area along the Gulf of Mexico. They are overlapped on the north by the glaciated area.

They consist of broad plains of from low to moderate relief with a few low plateaus. The principal rivers are broad, slow-moving streams and the plateaus for the most part are low, well-rounded, and soil-covered. In other words, this is an area showing the effects of long-continued weathering and surface erosion.

The area intermittently covered by ancient seas in whole or in part contains bedrock predominantly sedimentary in origin. The interior plains comprise only comparatively small areas of violent crustal movement. Movement over most of the area has been slow alternating elevation and subsidence of the land surface with advance or recession of the shore line.

Local areas which have not been subjected to stream erosion and are underlain by limestone and similar rocks may and do contain deposits of residual gravel. Typical examples are the accumulations of flint nodules in a clay matrix so common in portions of the central west.

Stream erosion combined with surface weathering has collected and concentrated sand and gravel in present and ancient watercourses and their flood plains. In these areas the prospector will find his greatest source of sand and gravel in the beds and flood plains of the present rivers. However, he should not overlook the long abandoned beds, flood plains, and terraces of earlier watercourses. Reports of the U. S. Geological Survey and the State geological surveys will be of assistance to him in showing where these may be found. Geophysical methods may also be of assistance. (See p. 16.)

Plateau and Mountain Areas

Plateau and mountain areas comprise several separated sections such as the Appalachian and Ozark plateaus and the Rocky Mountains and Pacific Mountain systems enclosing the great basin and range area of the west. They are characterized by steep slopes, barren, or with light soil, on bedrock of predominantly igneous origin, with swift streams in narrow valleys.

In the geologically older sections such as the Appalachian, the mountain slopes are less abrupt and the contours more rounded. At the base of the Blue Ridge Mountains and to the southeast covering the north and western portions of Georgia, South and North Carolina, and Virginia, the topography is that of a comparatively narrow plain abutting the mountains in which the erosion has not yet completely rounded the contours of the ridges. The area is a nearly flat or broadly undulating land surface produced chiefly by the work of rivers assisted by weathering. In this section the old original plain has been elevated and is now undergoing a second erosion period in which the streams are cutting deeper courses.

In the Ozark Plateau region residual gravels may be found on ridges of resistant rocks, but commercial deposits will occur in the river beds and flood plains and in alluvial fans.

In the western mountain plateaus and ranges many complex conditions exist. In places isolated mountains and short ranges are interspersed with broad desert plains. In others the ranges are continuous with narrow steep valleys.

The desert sands are seldom of commercial value except where concentrated in deposits of comparatively small area by periodic desert streams. These streams are dry the greater

portion of the year but attain torrential dimensions during cloud bursts or periods of melting mountain snows. In consequence they often bring accumulations of coarse material long distances in a single season. They also frequently cut new courses, tearing up old deposits and building new ones.

Where narrow mountain valleys debouch upon broad foothill plains the rapid, heavy-laden mountain streams are forced to deposit their burden rapidly. In consequence they form alluvial fans or cones at the valley mouths. Ordinarily the channel is not so deep but that the stream can break out at times of high water and take a new route on a lower part of the cone. When deposition has gone too far in one place there is a shift in the watercourse to a new position, so that the cone is formed symmetrically, banked up against the mountain side.

If these cones coalesce they form a piedmont alluvial plain which spreads like an apron along the front of the range.

These cones or fans are accumulations of coarse and fine material but ordinarily contain little clay or silt. The velocity of the depositing stream has been too great to allow silt to settle and it is carried beyond to the plain below. There is occasionally some grading, particularly the accumulation of boulders at the base of the cone. These accumulations may be covered again by later finer material as the stream course changes so that the cone structure will contain irregularly placed accumulations of coarse and fine material throughout its mass.

These deposits are characteristic of the Pacific coast. They may extend for miles along the coastal range and are often hundreds of feet in vertical thickness.

In places the alluvial fans as originally formed were subsequently further eroded when the streams cut channels through them and redeposited part of the material at lower levels, leaving alluvial terraces. Such terraces are common in some of the high plateau areas where the original fans were formed by streams heading in glaciated mountain gorges and depositing glacial outwash material. With the source of this glacial material exhausted by the retreat of the ice the streams had less material to deposit and began cutting into the fan formation, redepositing it in lower fans. These latter formations are found in eastern Oregon, Washington, and southwestern Idaho.

A particularly interesting form of deposition occurs around the boundary of Great Salt Lake. This lake in former periods of geologic history was much larger than at present. In this earlier stage sand and gravel brought to it by mountain streams were deposited along the old shore line as beaches. As the lake was drained or evaporated these old shore lines were left as terraces and afford a plentiful supply of well-graded sand and gravel at the present time.

In the plateau and mountain regions the principal sources of commercial sand and gravel are in alluvial fans, terraces, flood plains, and river beds.

Coastal-plain Deposits

The Atlantic and Gulf coasts of the United States from New York to the Mexican border have been subjected to one or more gradual uplifts whereby the land area has risen with respect to sea level. Thus ancient ocean beds have been elevated to become coastal plains. These old sea beds were formed by the accumulation of gravel, sand, and silt eroded from adjacent land areas. Concentration has been accomplished by wave action, by ocean currents, and in part by the depositing streams. Considerable stratification is found, as well as complex cross-bedding. Some cementation has taken place whereby material deposited as unconsolidated sand, gravel, or silt has become sandstone, conglomerate, or shale. In other cases no consolidation has taken place and the material has been elevated in its original form of deposition.

This uplift was a very slow process extending over long periods. Previously established watercourses on the original land surface continued to function during these periods and unless the rate of uplift was too rapid they maintained their elevation with respect to sea level. In effect they cut through the rising surface as fast as it was lifted. Those areas between watercourses being unaffected by stream erosion retained their undersea character. Thus, in coastal plains we find deposits which present all the characteristics of, and are, in fact, beach sand and gravel on the tops of hills.

Periods of uplift followed by periods of quiet allowed the sea to erode the raised bed and form terraces in the terrain. Some of these older terraces in Virginia and Maryland have been classed by geologists as of fluvial origin in the form of alluvial plains. Also in southern Georgia some geologists are of the opinion that the sands occurring there as the surficial mantle are of wind-blown or eolian origin rather than marine.

Rivers within coastal-plain areas are slow moving, broad, and shallow. Except in flood periods they transport only the finer sand and silt. Material brought down during a period of high water is deposited on a mud or silt bed and covered with more mud as the current again assumes its normal flow. Thus the gravel found in the beds of coastal-plain rivers is apt to be badly interbedded with fine sand and silt or clay.

The remains of old marine deposits will be found as dry-bank gravels in areas between drainage basins. Owing to the sorting action of waves they may be more or less graded as to size.

The Glaciated Area

The Canadian ice sheets extended (see fig. 1) southward in the Great Lakes region to the southern portions of Illinois, Indiana, and Ohio, covered most of New York the northern portion of Pennsylvania, and New Jersey and all of New England. To the west they covered nearly all of Minnesota and Iowa, northern Missouri, the northeastern portion of Kansas, eastern Nebraska and the east half of South Dakota, and all but the southwest quarter of North Dakota. Further west they extended only 50 to 150 miles south of the international boundary and there were many local mountain glaciers. The southwestern quarter of Wisconsin, singularly enough, seems to have been an island untouched by the ice although completely surrounded by it. (See fig. 1.)

In advancing southward the ice sheets moved immense quantities of material, much of it from the highlands of Canada and Labrador, but the greater portion from closer sources. In this advance they scoured out the valleys now occupied by the Great Lakes, and when they melted deposited their loads in terminal and ground moraines.

Their tendency was to cut off minor irregularities in previous surface topography, smooth the hills, and fill many of the valleys, leaving in the interior a comparatively level or gently undulating terrain, but with deep wide troughs controlling the axial movement of the ice, and to leave the whole area covered by an unconsolidated mantle of sand, gravel, and silt.

The glaciofluvial waters from the melting ice followed preexisting watercourses from the edge of the ice or formed new courses for themselves. Originally the direction of flow of some of these preglacial rivers may have been northward, but this direction was blocked by the ice and the flow reversed or diverted.

Subsequently these glaciofluvial waters cut through and began tearing down the glacial moraine deposits. Material picked up in this way was deposited later as outwash plains and terraces.

Glacial waters also formed another type of deposit. Ice melting on the surface or beneath the glacier formed streams which in turn melted more ice which not only augmented their

volume but cut channels through, in, and under the body of the glacier, liberating and picking up sand, gravel, and clay enroute. These streams emerging from the face of the retreating ice deposited their load as they fell. Some deposits were made by streams flowing in ice-walled channels or tunnels. As the ice melted the material was left as low, rounded ridges with their long axes parallel to the direction of ice movement. These are termed eskers.

The whole glacial area was thus covered by a mantle of unconsolidated drift, with deposits of sand and gravel, here and there especially along the valleys. Between the terminal moraine ridges are found broad, smoother tracts with low hills and some knolls, or ridges. These are ground moraines and eskers.

Taken as a whole these several types of deposits comprise a heterogeneous collection of sand, gravel, boulders, and clay.

Bordering some terminal moraines are broad, gently sloping, outwash plains of fairly well assorted sand and gravel. These usually front on terminal moraines and were formed as outwash plains by glacial water. Terminal moraines left by the retreating ice front dammed valleys and impounded watercourses to form the countless lakes characteristic of the topography of Michigan, Wisconsin, Minnesota, northern Pennsylvania, New York, and the New England States. The streams from the melting ice deposited much sand and gravel along their valleys where this material is now generally found in the form of terraces.

Outwash plains are typical of the deposits of Illinois, Indiana, and Ohio.

In South Dakota all the sands and gravels east of the Missouri River were brought by ice or glaciofluvial waters.

In Pennsylvania the glaciers brought rock material from Canada and New York State, and left it in moraines and glaciofluvial deposits.

The sand and gravel prospector has no problem of discovery for his material in this region. His problem here becomes one of search for quality. His object is to find the reworked or glaciofluvial deposits in preference to the moraines and eskers. However, the latter should by no means be overlooked, for their silt or clay content may be in such form as to afford little difficulty in its removal.

The beds of streams and some lake beaches and terraces afford promising sources for clean, sorted materials.

PROSPECTING

Before proceeding with the discussion of prospecting the following definitions are made in order that there be no misunderstanding of the meaning of terms used.

Prospecting is herein defined as the act of searching for, with the object of discovering, deposits of mineral.

Exploration is defined as the act of examining a deposit when found, with the object of determining roughly its size, shape, and value.

Development is defined as the process of preparing a deposit for exploitation, with the object of recovering its contents for sale or use.

The widespread and plentiful distribution of sand and gravel deposits coupled with the early laxity of specification requirements when the industry was young, rendered prospecting for those materials unnecessary. Discovery was a common occurrence through the agency of other unrelated activities such as the building of roads, railway rights of way, or canals, digging cellars and wells for houses, and drilling water, oil, and salt wells. As cosmopolitan communities grew, sand and gravel plants were erected to supply their markets. Prospecting for these deposits constituted the simple practice of examining existing evidence in the immediate neighborhood. With the advent of concrete and the increased demand for

aggregates, more and larger plants were erected. Consumption, however, remained in a more or less centralized market. Building construction centered around cosmopolitan areas, road construction radiated from those areas, and ballast was delivered to the railroads within their limits.

Construction, roads, and ballast made heavy demands on these original deposits and in many places depletion was serious. As knowledge of the art of making concrete grew, specifications became more and more rigid. Deposits previously suitable to market demands were found to require complicated treatment to meet changing specifications. In consequence, many deposits were abandoned as not containing sufficient material in reserve to warrant the expense of an elaborate treatment plant. This caused operators to cast around for new deposits. Many were opened and expensive plants were erected only to fail because the material proved unsuitable for the market. Other failures resulted because the operators erected plants on the new deposits identical in design with those just abandoned without realizing that the material in the new pit would require entirely different treatment. Many such plants erected by individuals were underfinanced and when it became apparent they were unsuitable the operator failed because of lack of funds to make the required alterations in design. New investors, many times with no knowledge of the business of producing sand and gravel other than that some men had made a profit from it, stepped in and bought these new plants at a reduced valuation. Some were successful after redesign, others were not. The fact remained, however, that deposits of sand and gravel were known to exist at these points and that plants were standing ready to operate. Such plants, to the initiate, are monuments of failure, but are intriguing to the novice as offering opportunity for rehabilitation and investment of idle capital.

Many of these failures could have been prevented if previous study had been given by adequate prospecting for the deposits and exploration when found.

Recently conditions have again changed. Railroads hampered by lack of earnings have radically curtailed ballast purchases. Building construction has fallen off badly. The gravel producer has been forced to concentrate his sales effort on highway construction. Here also conditions have altered. Where formerly highway construction centered and radiated from community centers the demand is now for intercommunity roads. This has created a market for aggregates at widely separated consuming points outside of metropolitan areas. In other words, the aggregate market has been decentralized.

Freight rates or transportation expense, always a large item in the consumer's bill, became of still greater importance as delivery points receded from old production centers. Aggravating this condition, increasing freight rates forced many operators to revert to auto-truck delivery over paved highways to new projects.

This condition afforded an excellent opportunity for the opening of new deposits favorably situated, with respect to truck or rail haul, to this scattered highway construction. Again many new plants were built. Rigid and differing specifications requiring treatment plants of elaborate design coupled with an unprecedented growth of consumption and the inertia of thought respecting radical departure in design, caused operators to follow previous precepts in the design of these new plants. In consequence many were built near the site of new road construction after plans entirely too elaborate and for much too great a tonnage. Upon completion of the particular road project which instigated their erection their owners found themselves with deposits of material and plants to treat them but without local markets. This forced them to attempt to extend their field by reducing prices. Thus was ushered in a period, of intensive, and many times destructive, competition.

Again, had better forethought been expended in prospecting and exploration in conjunction with a more far-seeing study of markets there would have been less liability for failure and overcapacity construction.

At present there is a decided movement toward decentralization of production to meet decentralization of consumption. This is exemplified by the growth in the number of small wayside pits erected by new producers, by highway contractors to supply their own jobs, and more recently by operators of large centrally located plants to compete with the two previous types in an effort to hold their market territory.

This trend has resulted in the improved design of small portable or semi-portable plants. These are being erected with the sole purpose of supplying material for a certain construction project in which a material of definite specifications is required. These plants are designed to produce that material primarily and it is not intended that they should be capable of supplying material to meet a multiplicity of specifications.

The opening of these new deposits for more or less temporary operation requires first a careful search for locations within economic or competitive shipping distance of the project they are intended to supply, and second, a careful exploration to determine their size, and suitability. There are practically no sand and gravel deposits in existence to-day capable of supplying any single construction specification without some form of treatment. Size gradations of natural deposits must be altered to meet engineers' specifications. This means the elimination of certain sizes and a recombination of others. These eliminated sizes must in many cases be wasted. In this the small plant supplying a single project is at a disadvantage because it has no outlet for these wasted materials. Soft particles must be removed, as must clay and silt also. This requires washing and at times hand picking. Washing requires suitable supplies of water. The type and design of the production equipment will depend upon the physical characteristics of the deposit. The design of the treatment equipment will depend equally upon the physical character of the material in the deposit and the gradation and specification desired. The screen sizes must be correlated to produce the desired gradation from the raw or washed material. The method of washing must be suited to the quantity of material that must be removed. Assurance must be had that the water supply is adequate and suitable.

All of these items of study are based on knowledge which can be and should be obtained by a careful program of prospecting and exploration. No plant should be erected without this preliminary search and study. The extent of the prospecting and exploration campaign will necessarily be adjusted to the size and complicity of the market it is desired to supply.

Prospecting Methods

Prospecting for sand and gravel is usually done by one of two general methods: The direct method, wherein the prospector sets out to find a visible deposit; and the indirect method, in which he relies upon topographic or geologic knowledge to guide him to likely localities.

In the direct method the prospector endeavors to find a deposit which outcrops above the soil or water level, is visible in clear shallow water, can be seen in railroad or highway cuts, or is known to exist from data collected in the digging of cellars, wells, or post holes. This method involves a great deal of time in the observation and search for visible outcrops and in the collection of excavation information. A large percentage of the results will be negative. In such a search the prospector must systematically examine the whole area.

The indirect method presupposes a knowledge of the structural geology of the region under investigation. This method is primarily one of elimination in which the prospector avoids all that area which has unfavorable topographic or geologic structure. He thereby confines his direct examination to only that area which his knowledge indicates may contain commercial material. His first procedure in this method is to collect all available data on the geology and physiography of the territory. The published reports of Federal and State

geological surveys will be of considerable assistance at this stage. These reports need not necessarily deal with sand and gravel resources only, but may relate entirely to geologic structure. The interpretation of the causes and results of the local structural history will furnish the key to likely sources. Upon locating favorable structures a knowledge of the genesis of the formation may give valuable information as to the character and value of the deposit itself. In such a search much of the prospector's time and money are saved by his knowledge of where to search without the necessity of examining the whole region.

Table 1 shows the principal guides to surficial examination for sand and gravel deposits.

Supplementing and in further explanation of the following table the following comments are in order.

Topographic Features

Topographically the earth's land surface may be divided into two general divisions: One of high relief or mountainous areas, and one of low relief or broad valleys and plains. In the first, erosion is active and products of erosion are rapidly removed with comparatively little deposition occurring. In the second, the erosion products of the first are deposited and erosion is very slow. The second division may be further subdivided into areas in which the material has been deposited by transporting agencies such as ice or water and others where material is left in place by weathering.

Therefore, regions of high relief being deficient in conditions favorable to deposition are not as promising territory for the prospector as those of low relief. This, of course, is a general statement and must not be taken as covering all conditions. For instance, swift mountain streams may debouch from narrow valleys into broad piedmont plains with suddenly decreased slope. This causes deposition as alluvial fans and plains which may be formed in mountainous regions, only to be later reworked by the continuing stream action and transported to and deposited on lower plains.

Low, rounded hills in glacial regions suggest moraines or eskers, depending on the relation of their long axes to ice movement. Rounded ridges outside of glacial areas suggest residual deposits.

Gently sloping plains at the base of mountain ranges suggest alluvial fans or plains. Similar plains not contiguous to mountains but in the vicinity of glacial territory suggest outwash or fluvioglacial plains. Flat-topped plateaus in coastal-plain areas suggest marine deposition.

Rivers with swift currents and narrow valleys indicate small bar deposits of coarse gravel and boulders. Narrow, moderately swift streams in wide valleys indicate gravel and sand bars in their beds and terraced valley walls. Broad, slow-moving rivers traversing flat or gently sloping plains indicate fine gravel with accumulations of sand and silt.

The grade of a drainage system will vary from steep slopes in the mountains to zero in the valleys. The transporting power of a stream is dependent on the velocity of the current, which in turn is dependent on the grade and character of the stream bed, the height, character, and alignment of the banks, the depth and volume of water flowing, and the amount of material being transported. Old publications state that the size of a particle which can be transported by a stream varies as the fifth power of the velocity. Van Wagenen⁴ gives the following table:

4 - Van Wagenen, T. F., Manual of Hydraulic Mining: D. Van Nostrand, N. Y., 1880, p. 88.

Table 1.- Key to sand and gravel deposits

Formation	Sites of deposition	Structure	Fine material	Coarse material	Associated material	Relations to underlying material
Residual	Regions of disintegration. Tops of low rounded ridges between drainage basins and outside glacial area.	No true bedding. Angular or spheroidal weathering. Heterogeneous mixture.	Disintegration sands and clays such as feldspathic clay from granite.	Well-rounded (spheroidal weathering) to angular particles with rough or pitted surfaces. Flint nodules from limestones.	Associated with the parent rock because there has been no transportation.	Boulders of weathering grade down into the unweathered rock. Differentially weathered deposits lie upon roughened surface of the parent rock.
	Fluvial	Varied texture. Sand lenses common; often cross-bedded. Elongate parallel to stream flow. Material accumulated in discontinuous layers. Beds vary in thickness. Sorting may be poor. Matrix may be so abundant that pebbles do not touch one another. May be hundreds of feet thick in places.	Poorly sorted. Angular to rounded grains. More apt to be rounded.	All sizes up to several tons in weight, but mostly less than 6 inches in diameter. Subangular to well rounded. Smooth surf-faces.	Sands and sandstones. Clay seams.	May lie upon eroded rock floor. Sometimes upon finer sediments.
Marine and lake	Deltas	Pebbles usually touch one another. Well sorted. Possibly definite arrangement. May be pell-mell structure. Sand lenses elongate parallel to shore line. Rarely over 100 feet thick	Clean sands fairly well sorted. Angular to rounded.	Well rounded, smooth with dull polish.	Sand and sandstone.	May rest unconformably on wave-scoured rock.
	Area originally covered by the ice	No true bedding. Isolated nests and small beds of sand. Unstratified mass of miscellaneous unsorted rock	Angular Decomposable minerals such as feldspar may be present. Rock flour containing sand grains may occur	Angular or subangular striated surfaces. All sizes.	May be associated with water-washed materials.	If unconsolidated the underlying materials are apt to be disrupted and contorted. If rock, it may be striated and grooved.
Glaciofluvial	Valley trains; outwash plains; eskers.	Similar to fluvial alluvial cones. Stratification good, poor or absent. Structure often pell-mell.	Poorly sorted; angular and subangular predominate. Feldspar may be present.	Typically subangular. Large striated boulders.	Sand or sandstones.	Glacial abrasion on bedrock below. May rest unconformably on other deposits.

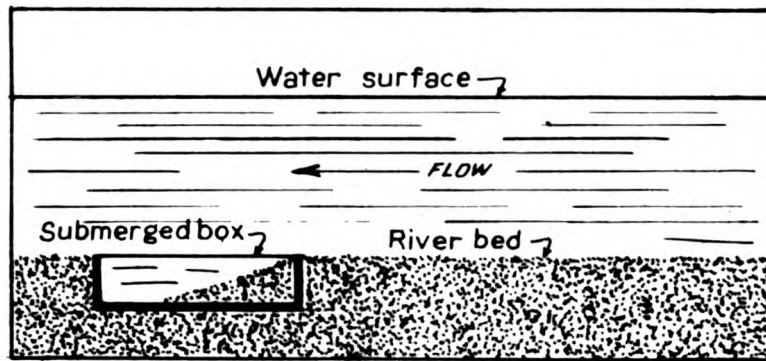


Figure 2.— Box set to test stream carrying capacity

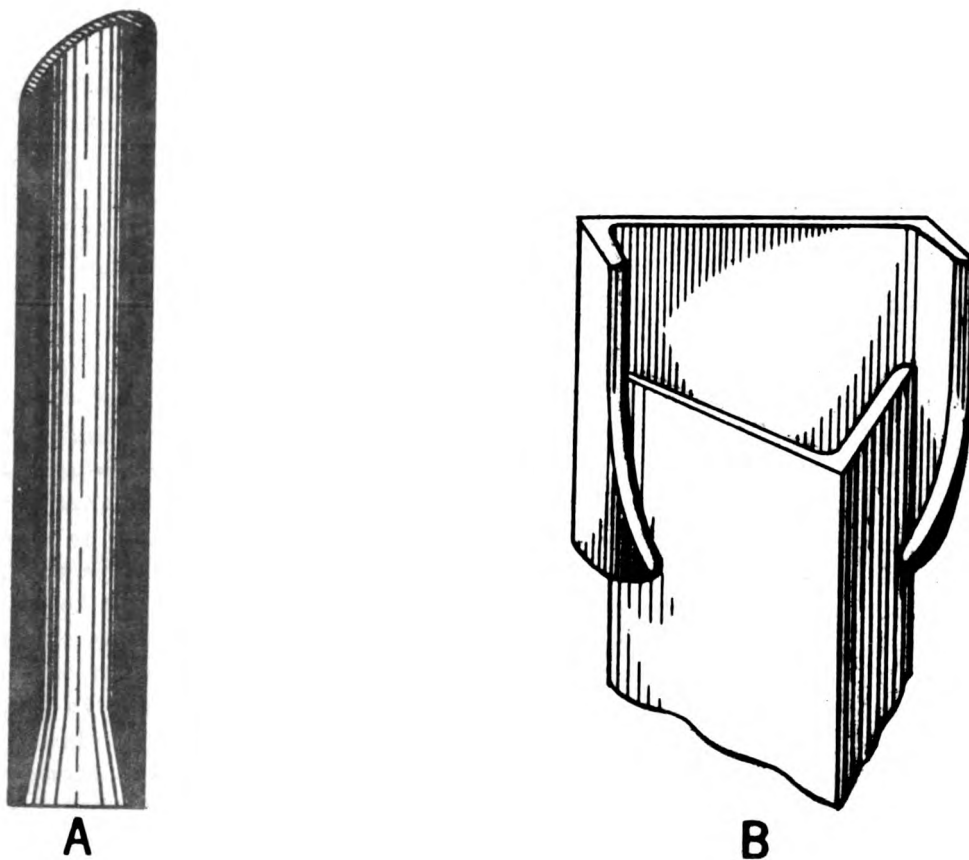


Figure 3.— A, Section of test-pipe bit; B, angle and channel

Table 2.- Transporting power of water in sluiceways

Velocity, f.p.m.	Material moved
16	Begins to wear away fine clay.
30	Just lifts fine sand.
39	Lifts sand as coarse as linseed.
45	Moves fine gravel.
120	Moves 1-inch pebbles.
200	Moves pebbles as large as eggs.
300	Moves boulders 3 to 4-inches in diameter.
400	Moves boulders 6 to 8 inches in diameter.
600	Moves boulders 12 to 18 inches in diameter.

Owing to the differences in influential factors the carrying power of water in streams will vary considerably and sluice experiments are not truly comparative. A similar table is quoted by Geikie⁵ as follows:

Table 3.- Transporting power of river currents

Velocity, f.p.m.	Material moved
15	Will just begin to work on fine clay.
30	Will lift fine sand.
40	Will lift sand as coarse as linseed.
60	Will sweep along fine gravel.
120	Will roll 1-inch pebbles.
180	Will sweep along slippery angular stones of the size of an egg.

Many times a rise of only 1 foot in a river will replace sand and gravel that required months to remove by dredging.

Very shoal or very swift water is not conducive of forming river bed deposits. Deep pools above or below shallow rapids are potential sites of deposits. The inside of curves in the river's course, the point of confluence of small tributaries with the larger stream, or the site of any other cause which tends to decrease the current flow indicates deposition.

A common method of testing the rate of deposition in a stream bed is to submerge a wooden box in the river bottom (see fig. 2) so that the upper edges are just flush with the bed. Observation of the time required to fill the box or preferably measurement of the amount caught in a given time calculated to the ratio between the width of the box and the width of the stream will give the information desired.

Gravel beds free from clay and silt offer favorable conditions for the free migration of underground water. Therefore in arid regions the presence of unusual vegetation often indicates the presence of underlying sands or gravels. As an example, in Georgia⁶ sand

5 - Geikie, A. J., *Class-book of Geology*: Macmillan & Co., London, 1902.

6 - Teas, L. P., *Preliminary Report on the Sand and Gravel Deposits of Georgia*: Bull. 37, Geological Survey of Georgia, 1921, p. 132.

deposits along the fall line are easily located by the growth of scrubby, sharp-leaved, black jack pines in an otherwise barren surface landscape. In other sections, such as parts of Texas, the presence of willow trees are indicative of subsurface water in gravel occupying stream beds long since abandoned by the present watercourses.

The prospector will do well, then, to observe first the topography and physiographic features of the surface, including vegetation where it may be indicative. His next interest is the physical character of the material exposed to view. He must then correlate these data with topographic information.

The composition, shape, size, and surface markings of sand and gravel particles are important in defining the origin and estimating the value of deposits. The presence of decomposable minerals indicates short, rapid transit from source to deposit without extended erosion. Smooth-surfaced, angular to rounded pebbles indicate alluvial deposits. Pitted or rough-surfaced gravels indicate residual deposits. Angular to rounded particles with striated or grooved surfaces point to glacial action. Subangular to well-rounded gravels with smooth surfaces having a dull polish indicate marine deposition.

Geophysical Prospecting

So far as the writer is aware geophysical methods of prospecting for gravel deposits have not as yet been used by operators. During the summer of 1931 the Illinois State Geological Survey conducted some experiments with the relative resistivity method in locating gravel. This work was conducted by M. King Hubbert, Instructor in Geophysics, Columbia University, and the results were published as Technical Publication No. 463 by the American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York.

One test made to locate the depth of bedrock below the surface gave negative results and the depth could not be determined. Unexpectedly, however, differences in resistivity were marked at two stations, and this information combined with a knowledge of the local geology indicated the presence of a sharply defined gravel deposit, probably in the form of an ancient river channel.

In another test one station showed an abnormally high value of apparent specific resistivity indicating a shallow highly resistant body underlain by a relatively better conductor. This again was interpreted as gravel by applying a knowledge of local geology.

In order to check these results, experiments were made upon land known to contain gravel previously outlined by test pits and wells. The resistivity test coincided almost exactly with the known gravel area. For details of these tests the reader is referred to the previously noted publication.

From these results it would seem that geophysical methods have a place in the field of gravel prospecting, especially in the location of deposits otherwise hidden from surface examination.

EXPLORATION

The impression that the work of the prospector ends with discovery of a promising deposit is unfortunately far too prevalent. On the contrary, with such discovery the work of the prospector has only begun. His job from here on is to demonstrate that his discovery has a commercial value. This involves a careful examination of the surface exposures, followed by a similar examination of the material below the soil mantle or clay overburden. The size or extent of the deposit is important not only to insure sufficient material to supply the market but to ascertain what possibility there may be for competitors to locate on and operate portions of the deposit beyond the property leased or owned by the operator.

Of equal or greater importance, however, is a careful sampling and testing of the material to ascertain thoroughly and accurately its natural size gradation and physical characteristics.

If exploration is thorough, the prospector will have obtained the necessary data on which the operator may pass intelligent judgment on such questions as whether the deposit is sufficiently large to operate, whether it contains the necessary materials to fill specifications for markets within shipping distance, whether there is sufficient material available, how much material must be wasted and the locations of the best sites for waste dumps, and, in addition, the type of equipment best suited for its exploitation, the best method of attack, the proper location for the treatment plant, and the type of equipment needed in preparing the material for market.

None of these questions can be answered definitely by prospecting alone. Therefore the importance of exploration and its interrelation between prospecting and development is established and emphasized.

Prior to a discussion of methods of exploration, it seems advisable to define certain terms used in connection with sand and gravel production. Authorities differ in their definitions of the terms "clay," "silt," "sand," "gravel," "pebbles," "cobbles," and "boulders." As a matter of comparison some of these definitions are quoted herewith:

Sand is a mass of small rock fragments in an incoherent condition.

Gravel and coarse sand are synonymous.⁷

Sand may be defined as a naturally occurring incoherent, granular rock material less than 1/4 inch and more than 1/200 inch in diameter.

Gravel, similar except as to size.

Silt, similar except as to size.⁸

Sand is an incoherent material made up of particles of crushed or worn rock.

Silt, similar to sand except in size.

Clay, similar to sand except in size.

Gravel is an incoherent rounded to subangular rock material larger than 1/4 and less than 4 to 5 inches in diameter.

Cobbles, similar to gravel except in size.

Boulders, similar to gravel except in size.⁹

Sand in a commercial sense somewhat loosely means a material consisting of rock particles which are larger than 1/200 inch in diameter and smaller than 1/4 inch.

7 - Condra, G. E., The Sand and Gravel Resources and Industries of Nebraska: Nebraska Geol. Survey, vol. 3, pt. 1, 1911, p. 16.

8 - Martens, H. J. C., Sand and Gravel Deposits of Florida: 19th Ann. Rept., Florida Geol. Survey, 1926-27, 1928, p. 39.

9 - Teas, L. P., Preliminary Report on the Sand and Gravel Deposits of Georgia: Geol. Survey Georgia, Bull. 37, 1921, p. 1.

Gravel consists of somewhat rounded rock fragments larger than 1/4 inch and smaller than 2 to 3 feet in diameter.¹⁰

Wentworth makes a further size classification as follows:

	Diameter in inches	
	<u>Plus</u>	<u>Minus</u>
Clay.....	-	1/6500
Silt.....	1/6500	1/400
Sand: Very fine)		
Fine)		
Medium).....	1/400	1/12
Coarse)		
Very coarse)		
Gravel: Granule.....	1/12	1/6
Pebble.....	1/6	2 1/2
Cobble.....	2 1/2	10
Boulder.....	10	-

Sand indicates any granular rock material passing 8 mesh and retained on 270 mesh, regardless of chemical composition or manner of origin.

Gravels are fragments of unconsolidated deposits greater than 1/4 inch in diameter.¹¹

Nevin also makes a further size distinction as follows:

	Diameter in inches	
	<u>Plus</u>	<u>Minus</u>
Silt.....	-	270 mesh
Sand: Fine.....	270 mesh	70 do.
Medium.....	70 do.	20 do.
Coarse.....	20 do.	8 do.
Torpedo.....	1/8	1/4
Gravel: No. 1.....	3/8 round or 1/4 square	3/4 round
No. 2.....	3/4 round	1-1/2 do.
No. 3.....	1-1/2 do.	2-3/4 do.
No. 4.....	2-3/4 do.	3-3/4 do.

Sand.- The fine granular material (usually less than 1/4 inch in diameter) resulting from the natural disintegration of rock, or from the crushing of friable sandstone rocks.

10 - Wentworth, C. K., Sand and Gravel Resources of the Coastal Plain of Virginia: Virginia Geological Survey, Bull. 32, 1930, p. 119.

11 - Nevin, Chas. M. The Sand and Gravel Resources of New York, Bull. 282 New York State Museum, 1929, p. 7.

Note.- When used without a qualifying adjective, the term "sand" is generally understood to mean the product of the natural disintegration of siliceous or calcareous rock. Sand should be distinguished from screenings, gravel, etc. The size of the particle and other physical characteristics should be taken care of in specifications. The fine material resulting from the crushing of blast furnace slag is known as "slag sand."¹²

Merrill¹³ makes the following size classification:

	<u>Diameter, millimeters</u>
Gravel.....	About 2
Fine gravel.....	2 to 1
Coarse sand.....	1 to 0.5
Medium sand.....	0.50 to 0.25
Fine sand.....	.25 to .10
Very fine sand.....	.10 to .05
Silt.....	.05 to .01
Fine silt.....	.010 to .005
Clay.....	.005 to .0001

Silt.- The deposit of mud or fine earth from running or standing water.

Sand.- The finely divided material, generally of a siliceous nature resulting from the reduction of rock by natural forces to the size included under fine aggregate (minus 4 mesh).

Gravel.- Loose material containing particles larger than sand resulting from natural crushing and erosion of rocks.

Plum stone.- Same as gravel except ranging from 3 inches in diameter to 100 pounds in weight.

Cyclopean stone.- Same as plum stone except over 100 pounds in weight.¹⁴

These typical examples of both definitive phraseology and size present rather wide differences. The author presents the following definitions as embracing the concensus of opinion and use by the producers and consumers of sand and gravel:

Clay and silt.- The unconsolidated material, finer than 200 mesh, resulting from the natural disintegration of rocks.

Sand.- The unconsolidated granular material coarser than 200 mesh and finer than 1/4 inch resulting from the natural disintegration of rocks.

Gravel.- The unconsolidated material coarser than 1/4 inch and finer than 3 1/2 inches resulting from the natural disintegration of rocks.

12 - American Society for Testing Materials, Standard C58-23. Definition of sand by Committee E-8: Standards, pt. 2, 1930, p. 165.

13 - The Educational Series of Rock Specimens Collected and Distributed by the United States Geological Survey: U. S. Geol. Survey Bull. 150, 1898, Chapter by Merrill, G. P., p. 380.

14 - Committee on Nomenclature, American Concrete Institute Proceedings, 1923, p. 319.

Pebbles.- Identical with gravel.

Cobbles.- The unconsolidated material larger than $3\frac{1}{4}$ inches and smaller than 10 inches in diameter resulting from the natural disintegration of rocks.

Boulders.- The unconsolidated material larger than 10 inches in diameter resulting from the natural disintegration of rocks.

These various size classifications have been grouped in Table 4 for facility in comparison.

Exploration Methods

Exploration means examination. The object of exploration is to determine the size, shape, and value of a previously discovered deposit. Discovery may be merely the observing of the material lifted with a post-hole digger, the excavated material from a cellar or well, or visible in railway or highway cuts or similar exposures. Determination of size, shape and value requires actual physical examination of the material over the whole deposit, or at least over the area owned or leased. This requires opening holes or pits at intervals from which samples may be collected that will represent as nearly as possible the deposit as a whole. These samples must then be carefully tested in various ways and the results charted or otherwise recorded. With such information at hand the prospector reaches the most important step of all, which is a proper and intelligent interpretation of his results.

There are various ways of determining the extent of a deposit lying below thin overburden. If the soil be light one can often outline the gravel below by means of an iron bar. By churning, the bar can be forced through the soil by hand. When it strikes gravel a distinctly different metallic sound will be heard and usually the gravel will be more difficult to penetrate than the soil. The same means is often used for testing gravel bars in rivers in which the gravel is covered by fine sand or silt. Surface material may thicken in places beyond the reach of the bar and such areas would be reported as containing no gravel, although it might be present at greater depth. A length of $\frac{3}{4}$ -inch pipe to one end of which a steel point has been welded will extend the depth beyond that which can be reached by a solid bar. This method is applicable to the location of gravel from 2 to 15 feet below the surface. In river bars pipes have been used to locate gravel 20 feet or more beneath the surface of the water. The method is of principal interest in prospecting but is useful in delineating a deposit when discovered. It is inconclusive in that it recovers no samples and is useless in thick or heavy overburden.

Some operators are successful in exploring with the use of ordinary steel pipe 2 to $2\frac{1}{2}$ inches in diameter. One end of the pipe is forged or filed to a sharp edge with the bevel on the inside (fig. 3, A). A malleable-iron coupling or tee is screwed to the other end and the pipe is driven into the ground by wooden mauls or steel sledges. Short or long lengths of pipe are used, but with the latter platforms must be used to allow the men to reach the top end of the pipe in starting. Old diamond-drill rods can be used for this purpose. Ordinary pipe in short lengths with couplings of larger diameter than the pipe offers greater resistance to both driving and pulling than the drill rod with its flush joints.

The pipe is pulled, held over a wooden or steel platform, and tapped with a light hammer. As the material falls out the pipe is moved in a straight line. In this way the material brought up in the pipe is left in a continuous pile roughly representing its position in the ground. It can then be examined in whatever interval is required.

By forming the bevel of the cutting edge on the inside, the material entering the pipe is compressed as the pipe is driven. This helps to retain it when the pipe is pulled. Some prefer to enlarge the cutting end beyond the pipe diameter.

I.C. 6868.

Table 4 - Size classification of rock-disintegration products by various authorities
(Diameter in inches or mesh)

Authority	Clay		Silt		Sand		Gravel		Pebbles		Cobbles		Boulders	
	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
8 Martens, J. H. C.	-	-	-	200 mesh	200 mesh	1/4 inch	1/4 inch	-	-	-	-	-	-	-
9 Teas, L. P.	-	250 mesh	250 mesh	100 do	150 do	1/4 do	1/4 do	4-5 inch	-	-	4-5 inch	10 inch	10 inch	48 inch
10 Wentworth, C. K.	-	1/6500 inch	1/6500 inch	1/400 inch	1/400 inch	1/12 do	1/12 do	2-1/2 do	6 mesh	2-1/2 inch	2-1/2 do	10 do	10 do	-
11 Nevins, Chas. M.	-	-	-	270 mesh	270 mesh	8 mesh	1/4 do	3-3/4 do	-	-	-	-	-	-
12 American Society for Testing Materials	-	-	-	-	Not given	1/4 inch	-	-	-	-	-	-	-	-
13 Merrill, G. P.	0.0001 mm.	0.005 mm.	0.005 mm.	270 do.	270 mesh	18 mesh	18 mesh	-	-	-	-	-	-	-
14 American Concrete Institute	-	-	-	-	Not given	4 do.	4 do	3 do	-	-	Plus stone 3 inch 100 pounds	Cyclonean stone 100 pounds	-	-
Thoenen, J. R.	-	200 mesh	-	200 do.	200 mesh	1/4 inch	1/4 inch	3-1/2 do	Same as gravel	3-1/2 do	10 inch	10 inch	No limit	-

In dry deposits free from clay it is sometimes difficult to recover samples, as the gravel falls out when the pipe is pulled. Operating in material below the water table often has the same result, even with considerable clay present. In dry banks, however, with sufficient clay present to bind the core the pipe works fairly well.

In deposits containing many cobbles or boulders the pipe is not successful.

This method at best is but a preliminary test and should in no case be considered conclusive. When intended and used as a preliminary test only, it is a valuable means of both outlining a deposit and collecting a rough qualitative sample.

Some operators use this method to determine the depth of overburden only. They pull the pipe as soon as it strikes the gravel. The author has no knowledge of any attempt to ascertain the thickness of a deposit by this means. The pipe may be used to depths of from 5 to 30 feet or more depending on local conditions.

Earth augurs or post-hole diggers are often used both to determine the thickness of overburden and to obtain samples of the gravel.

Neither is very successful in penetrating the gravel to any considerable depth but they do obtain information regarding the amount of overburden and a rough sample of the top of the gravel.

One Texas operator is reported as using a machine-driven post-hole digger cutting a hole 16 inches in diameter.¹⁵ The machine is operated by a gasoline tractor and digs from 1 to 5 feet per minute in clay overburden. It is not successful in digging gravel nor in ground containing boulders.

A recently patented method of obtaining subsoil cores is described in an article appearing in the March 3, 1932, issue of the Engineering News Record. The method consists of driving a 4 by 4 by 5/8 inch angle vertically into the ground at the desired point. A 7-inch (20-pound) channel is then driven alongside the angle in such a position that the channel web spans the outstanding legs of the angle. The two shapes are then pulled and the enclosed material is removed intact.

The lower end of the channel has the flanges turned in for a short distance so that it will overlap and follow the angle as it is driven. Figure 3, B illustrates this combination.

The equipment necessary consists of a portable crane, for erection and mobility, an air-pile hammer with suitable compressor, a pair of wood or steel leads set on a spread timber foundation for driving the steel shapes, and a pair of 6-sheave blocks for pulling.

When the shapes are removed from the ground they are laid down and separated by slipping the channel a few inches one way until the turned-in flanges disengage the angle. The channel can then be lifted off, leaving a core of the material passed through in the angle open for inspection or sampling.

This method encounters the same difficulty as pipe driving when used in ground containing large boulders. It is also limited in depth to single lengths of the structural shapes. These have been successfully used to depths of 40 feet, however. A further difficulty in its use is the necessity for an air compressor and pile hammer. Possibly this might be overcome by an adaptation of churn-drill equipment to drive the shapes. In any event, the method has interesting possibilities and should not be overlooked in selecting exploration methods.

The churn drill is used by many operators with or without casing in exploring gravel deposits. By careful drilling and keeping the casing close to the bottom of the hole, fairly accurate information can be obtained. If the casing is not kept close to the bottom of the hole there is grave danger of contaminating the sample removed from the bottom with material falling into the hole from above. This danger is aggravated by the churning action of the

15 - Hyde, W E, Mining Treatment Methods and Costs at the East Texas Gravel Co 's Deposits: Information Circular 6537, Bureau of Mines, 1931, 8 pp

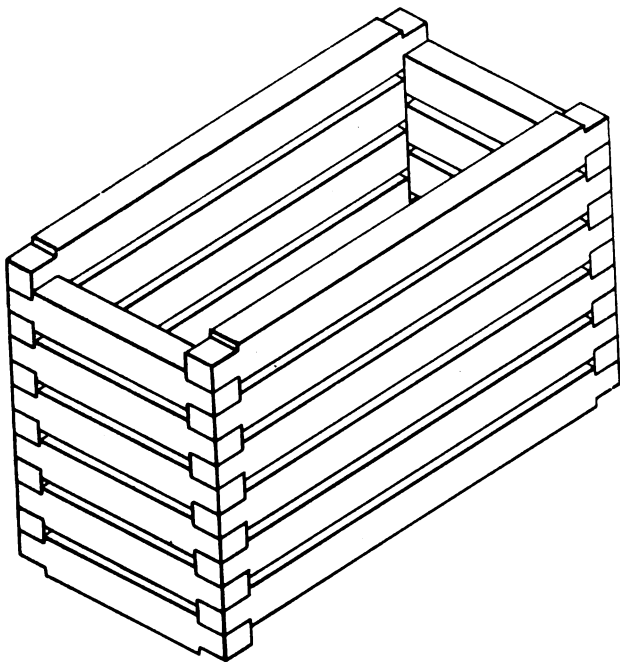


Figure 4.- Crib timbering

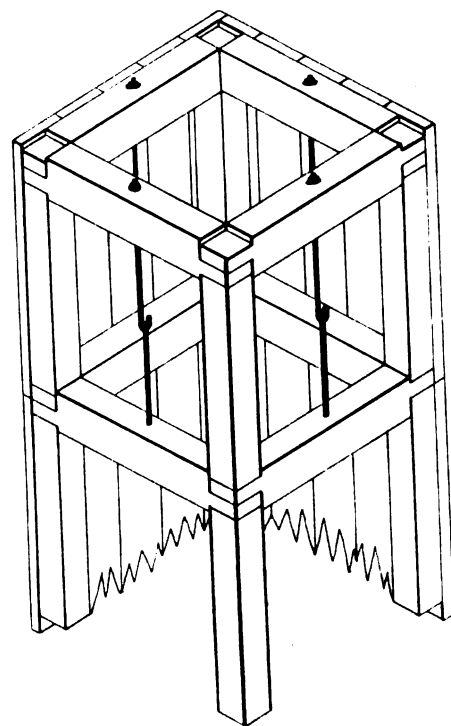


Figure 5.- Square-set timbering

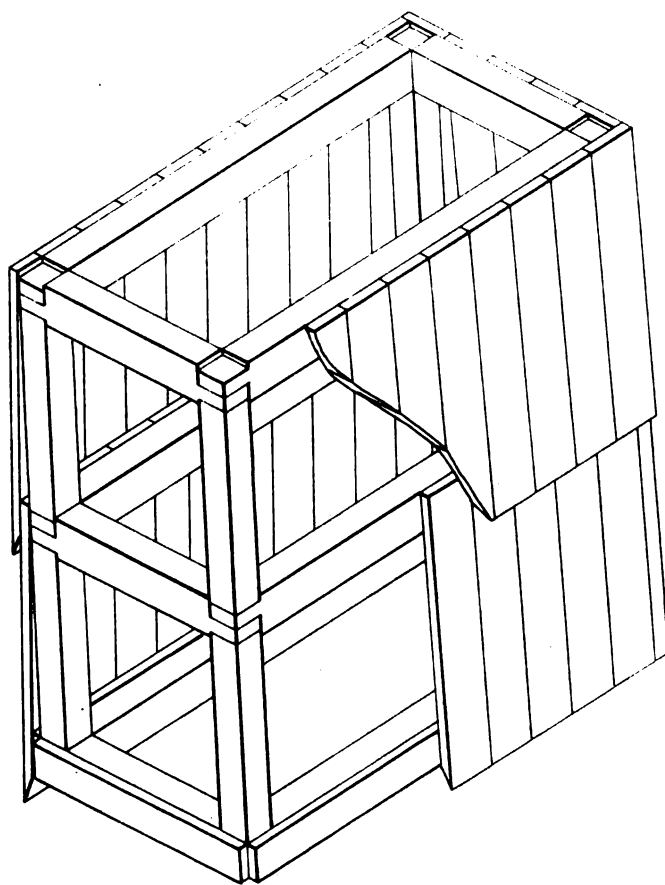


Figure 6.- Fore-pole timbering

drill itself and the whipping from side to side of the drill cable. By keeping the casing driven close to the bottom and cleaning the hole at short intervals the material brought up in the bailer will represent quite well the material passed through. Churn-drill holes in gravel should be cleaned out and the casing driven down at 2-foot intervals at most.

For exploration purposes the gasoline-driven, caterpillar-traction churn drill is perhaps the most popular type of machine. It is mobile and fairly cheap to operate. It will obtain information as to the depth of overburden and thickness and quality of gravel when the vertical thickness is not too great. It can be successfully used to depths of 50 feet or more. In some deposits where the subsurface water level is shallow, the churn drill is depended upon as the only successful means of exploring below water level. In some localities the casing is driven below the drill and the latter is used only to break up the inclosed material ahead of the bailer. This produces a more accurate sample but is not suitable for all cases because of the difficulty in driving the casing in unbroken ground.

In some ground that can be penetrated by driving casing the drill may be eliminated and a specially constructed flap valve bailer used. The lower or cutting end is fitted with a 3-pronged tempered cutting edge. Fastened to the drill cable it is churned up and down, thus breaking up the material inside the casing, and by means of the flap valve at the bottom the sample is removed by the bailer. This type of equipment may be operated by hand instead of a well drill. In this case the cable is brought up to a tripod erected over the hole and back to the ground where two to six men furnish the motive power, depending on the size of equipment used. The casing and bailer method has many advocates for sampling material below the water table, but by some operators it has been discarded in favor of the churn drill.

A modification of the casing and bailer method has been made by an equipment manufacturer. This consists of a small orange-peel bucket operating inside the casing. The bucket is operated by hand with cable and tripod the same as the bailer. As before, the casing must be driven ahead of the bucket, which is not always feasible. Where it can be used, however, this method should obtain accurate samples. As with all methods involving casing it is not successful where boulders are encountered. Its principal field is in dry material above the water table. Below that point the bailer is faster.

The preceding methods are what may be called preliminary only. They are recommended for outlining the boundary of a deposit and for obtaining preliminary rough samples. None of these methods are recommended for accurate testing in respect to gradation or quality. The only reliable and accurate method of exploring land deposits of sand and gravel is by means of test pits.

Test pits may be dug by hand or by mechanical means. Ordinarily, however, they will be dug by hand. A cross section of 3 by 5 feet makes an economical size in starting at the surface. One man can cut these to a depth of 7 feet. Beyond that another man is required at the surface to shovel material back from the edge of the pit. When the gravel is reached, test pits are usually contracted to a 3 or 4 foot circular cross section. In this operation the man in the pit uses a shovel with the handle cut short to load a small steel or wooden bucket containing from 1/2 to 1 cubic foot of material. His partner at the surface lowers an empty and hoists the loaded bucket by hand or with a windlass. In some deposits such pits can be sunk to 25 or 30 feet without timbering. In others where the gravel is loose, timber may be required at the start. There are several methods of timbering that may be applied to these pits. Several are illustrated in Figures 4, 5, and 6.

Figure 4 shows a common method in which old railroad ties may be used. This type is called cribbing, and there are various ways of applying it which differ only in detail. Cribbing is built upward from the bottom. This requires that the excavated ground will stand without caving for some distance. In starting the timbering, bearer sets are first inserted

to support the crib. These are framed the same as are the short timbers in the crib except that the ends are left from $1\frac{1}{2}$ to 2 feet longer than the width of the crib itself. Holes are dug in the walls of the pit and the bearer timbers inserted. Then the regular crib timbers are built up as shown in the figure. Each may be spiked to the one below.

Mortises and tenons may be cut so that the timbers touch one another, making a tight wall. Material may be saved, however, by leaving a space between the timbers equal to $\frac{1}{3}$ the horizontal width of the timber. This space will not allow material to come through into the shaft except in ground under heavy pressure or in material similar to quicksand. As illustrated, 6 by 8 inch ties are used laid on edge. Shoulders are cut $1\frac{1}{2}$ inches deep on each side, leaving a 5-inch tongue. At times notches are cut halfway in each timber with no shoulder on the other side, but this method does not provide as much strength to resist pressure as the framing illustrated.

The pit is sunk as far as it safely can be without caving. The cribbing is then placed and a second lift is excavated, after which a second section of cribbing is placed.

Where the walls of the pit will not stand alone over a distance of 3 or 4 feet, cribbing can be advanced downward with the excavation by using 2 or 3 inch plank. In this method the planks on end and side are alternated in length from inside to outside crib measurement. Each plank is nailed flat to the one above, and the whole hung from bearer timbers on the surface. This provides a tight wall from which little timber can be salvaged. No way is left to inspect or remove samples from the material passed through.

With open cribbing as illustrated, check samples can be taken from any depth at any time, and often the timber may be removed and used over again in another pit.

Figure 5 shows a common form of square-set shaft timbering lagged with plank. This method requires less board feet of lumber and can be advanced as the excavation proceeds. It requires more care in framing. Side shoulders are cut 1 inch deep and tongues are left 3 inches thick. Horizontal members may be 6 by 8 inch ties on edge with 6 by 6 inch posts, although ties may also be used for posts by cutting shoulders longer on one side. The sets are hung from bearer timber on the surface by hanger bolts as shown and a set is added and lagged as excavation proceeds at the bottom.

In ground which will not stand by itself the forepole method shown in Figure 6 is employed. The bearer timbers are placed on the surface and the first timber ring is bolted to them. Plank lagging is cut to reach slightly below the second set and is sharpened to a wedge shape with the bevel on one side only. The lagging is then started with the bevel side of the wedge to the timber and driven down to place with mauls. With lagging driven all around the ring set the ground inside is dug out until posts and the second ring can be set and bolted. A second set of lagging is then driven ahead as before. Very heavy ground may require lagging of double length in order that it may be driven outside the lower ring but inside the next above. Thus the upper end is held in by the ring and will prevent ground pressures from forcing the lower ends too far in to place the new ring of timber.

Lagged sets provide solid walls but single planks may be removed to collect vertical samples.

A more or less recent evolution in constructing the timbered test pit is the use of cylindrical steel casing instead of timber. This casing is either slipped down as a unit and a new section added at the top as the bottom is lowered or the new section is added at the bottom. One operator in Michigan reports a cost for this method of \$1.50 per foot with the work done on contract.

Shallow pits designed to penetrate the overburden and extend into the gravel only part way are often dug with portable cranes mounted on caterpillar tractors or with drag-line machines. These machines obviously can not operate in pits of small cross section, hence they can not reach the same depths as timbered pits without digging an excessive amount of

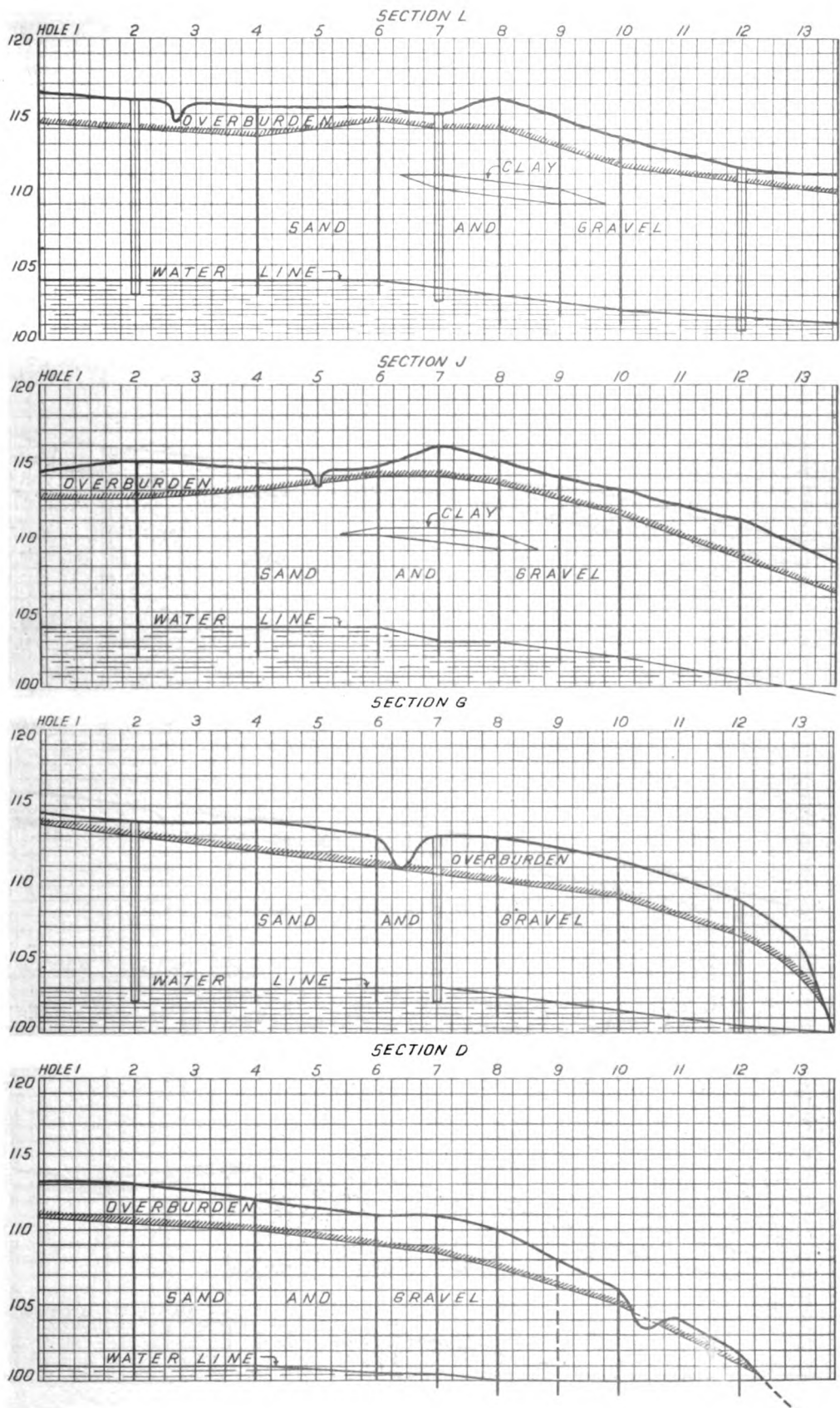


Figure 7.- Sections of deposit, showing character of material encountered by test pits and drill holes

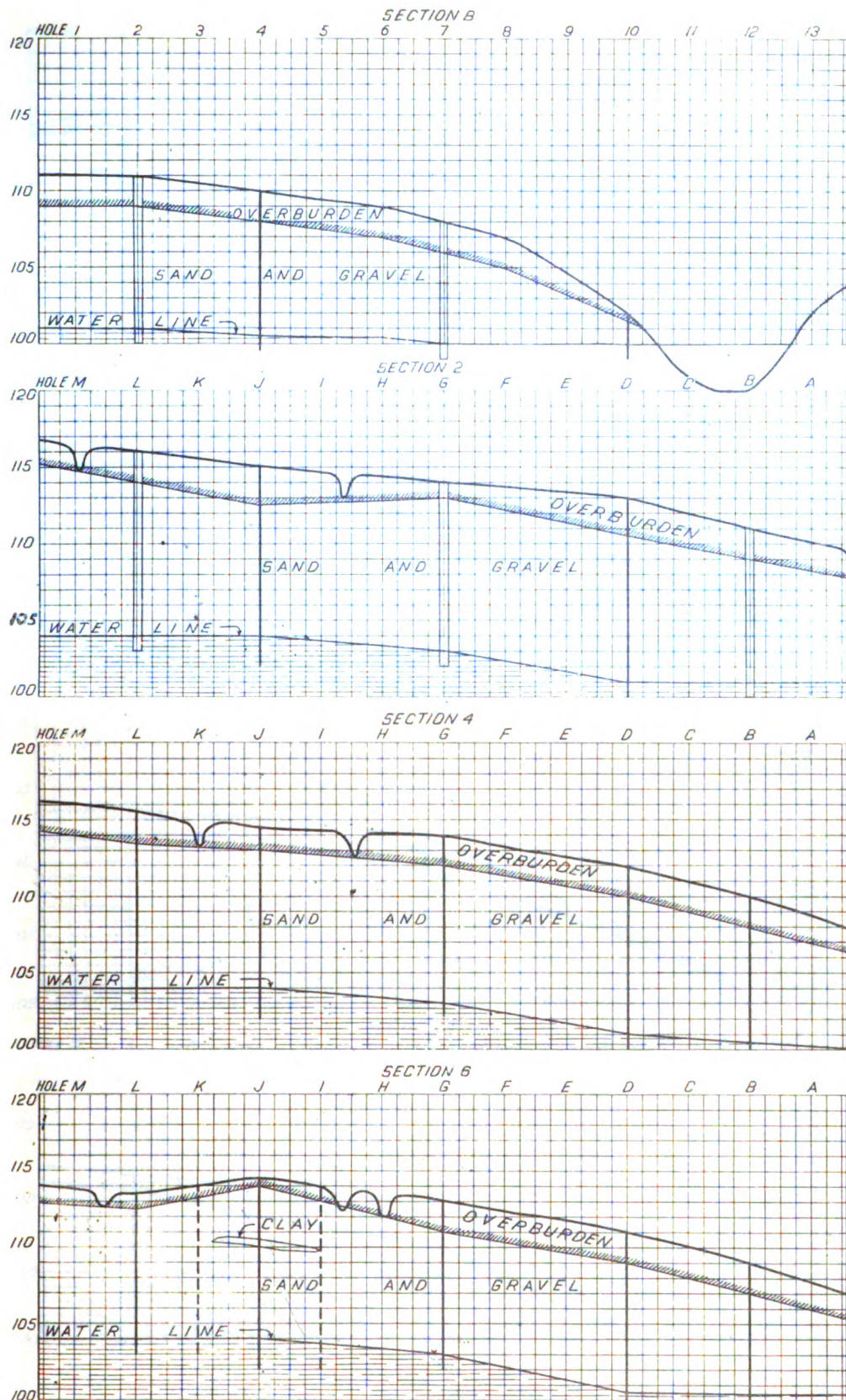


Figure 8.- Sections of deposit, showing character of material encountered by test pits and drill holes

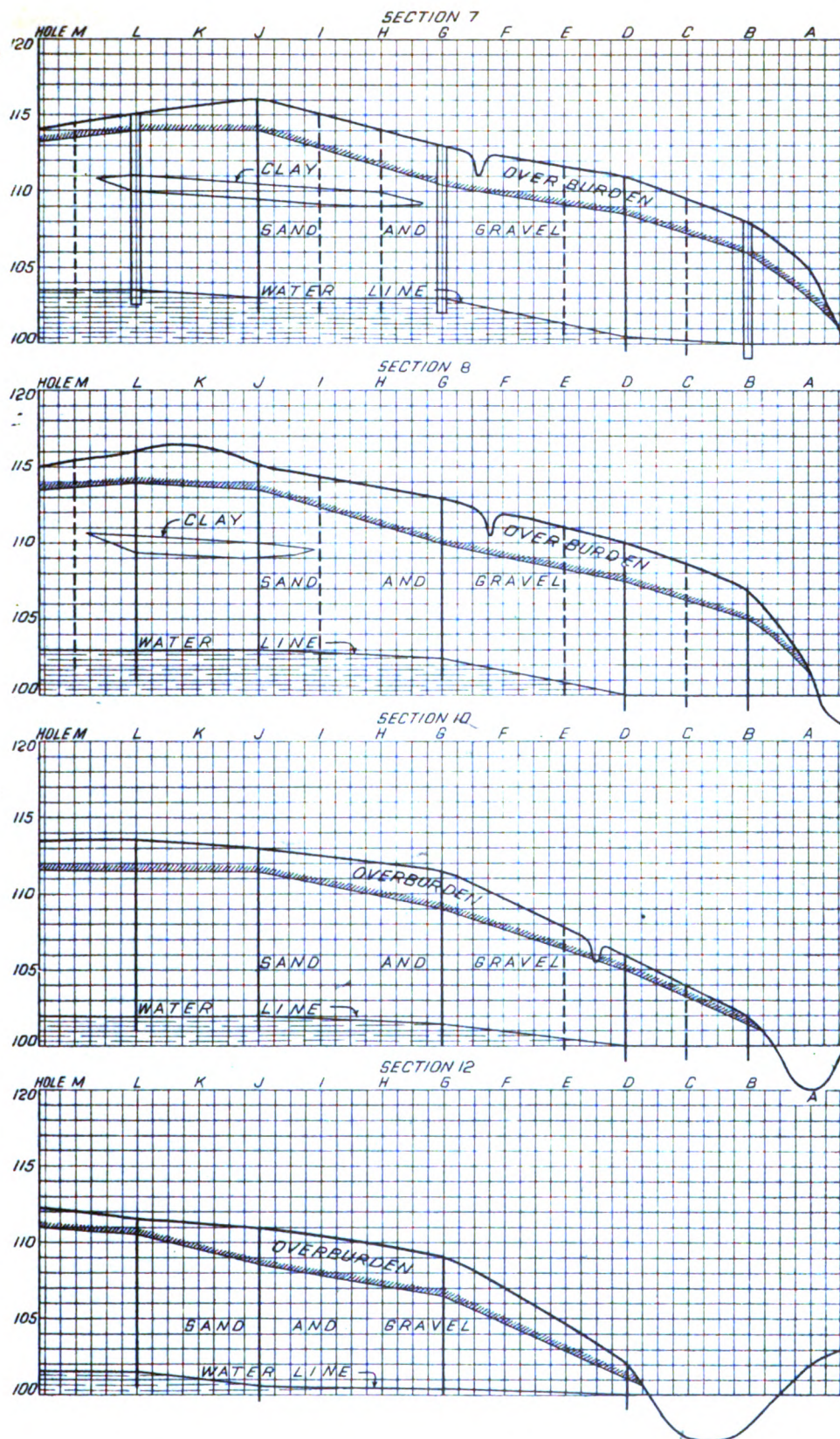


Figure 9.- Sections of deposit, showing character of material encountered by test pits and drill holes

material to provide the necessary slope to the walls to prevent caving. Because of this extra digging they are necessarily more expensive to use in reaching the bottoms of deep or thick deposits.

Test pits afford a means of entering and examining a gravel deposit not offered by any other device. They are more expensive to dig than post holes or churn-drill holes, but their accessibility for obtaining accurate information justifies the additional cost.

Ordinarily when water is found, the quantity is too great to permit dewatering the pit by pumping. In this eventuality the test pit is at a disadvantage.

Combination Methods

Various combinations of methods have been employed successfully, as for instance where test pits are sunk to the water level and exploration continues below by churn drill. Another combination is to use the small orange-peel bucket to the water level and follow with the bailer.

Drag lines and cranes have been used to dig shallow pits in the bottom of which timbered pits are sunk by hand.

Another type of combination is predicated upon cost over large areas. In this combination test pits are sunk through the deposit or to the lowest working level. These pits are spaced at rather wide intervals. Between them pipes may be driven or churn drills employed to test the deposit at intermediate points. In this manner erratic changes in the deposit may be spotted and where irregularities appear in the intermediate drill holes they may be replaced by additional test pits to gain a more accurate sample. This latter method is strongly recommended for accurate exploration.

For accurate results the location of test pits or boreholes must follow some systematic plan. If they are spotted indiscriminately over the land surface, considerable difficulty will arise in interpreting and correlating the information obtained from them. If, however, they are located after a regular geometric design, the resulting calculations are facilitated. (See figs. 7, 8, and 9.)

There is much divergence in personal preferences as to the most economical system of spacing test locations. Some prefer to start with post-hole diggers, pipes, or churn drills and when the whole tract is drilled out to check results by digging test pits where drilling has indicated their need. Others start by digging the test pits at rather wide intervals and follow this by check drilling between pits.

Figure 10 represents a 40-acre tract of land with test holes laid out on the corners of 200-foot squares, and with the border holes 60 feet within the boundary.

Figure 11 represents the same tract in which exploration has been started by digging test pits on the corners of 500-foot squares. In this case the border tests are 160 feet from the boundary.

In Figure 10 49 holes are required to complete the first test. If considerable variation occurs in the information obtained from any two adjacent holes as they are sunk, another hole should be put down between them. In this manner, should any hole cut through a clay seam or lens of fine sand not shown in adjacent holes, the extent of this irregularity may be outlined by drilling the eight holes on 100-foot squares left undrilled in the original 200-foot square system. This is illustrated by the "X" marks surrounding hole I-7 in Figure 10. This hole is so designated because it is the point of intersection of an east-west line through I and a north-south line through 7. When a deposit is of such nature that sudden changes of content are found to occur throughout its extent, it may be necessary to spot holes even closer than 100 feet.

So far in following the drill plan of Figure 10 no accurate samples of the deposit have been obtained. The information has indicated the depth of overburden, and the location of irregular variations in the material. The final check will be made by digging test pits at those points where information is needed as deduced from the drill holes.

In Figure 11 the test pits have been put in first. Samples from these pits are carefully examined and tested and where discrepancies occur between the material in two adjacent pits, test holes are drilled between them at 100-foot intervals. In this way the material brought to the surface in drilling may be sufficient when correlated with that from the pits to interpret satisfactorily the meaning of the change between pits. If not, other pits should be dug where one or more holes were drilled.

No hard and fast rule can be laid down as to the arrangement of holes nor the minimum distance that should be left between them. The final result must be arrived at by a study of the cumulative facts as developed by the drilling or test pitting tempered by the knowledge of the engineer or operator.

In order to obtain maximum results from a series of test holes or pits, the data obtained must be recorded in a systematic manner.

As a first step, the operator should obtain a topographic map of the property to be tested. The U. S. Geological Survey has mapped a large part of the more settled area of the country and these topographic maps may be obtained from their office at Washington at nominal cost. Where such topographic maps do not exist, the only recourse of the operator is to the engineer. Property maps without contour lines may be used and holes spotted thereon by the engineer. He can then construct the topographic map from the elevations taken while spotting the holes. As the holes are drilled or the pits dug, the information they afford should be plotted on the map or on notes which are referred to their proper location on the map. With this data complete, the next step is the drafting of vertical sections along lines of tests. These present graphic pictures of what has been discovered and are more easily read than a series of penciled notes.

As an example, Figure 12 has been drawn to represent a topographic map of a 40-acre tract. The border rows of holes have been laid out 60 feet from the boundary as in Figure 10. Intermediate rows of holes are plotted on 100-foot intervals, making 13 rows east and west after the letter designations A to M, and a similar series of rows running north and south corresponding to the numbers 1 to 13. In this manner any hole can be immediately spotted and located by its designation - for example, L-2 or G-7.

The eight test pits were then sunk and results recorded as follows:

Table 5.- Field notes of test pits

<u>Test pit No.</u>	<u>Feet</u>	<u>Elevation</u>	<u>Remarks</u>
<u>L-2</u>			
Surface.....	0.0	116.0	
Bottom of overburden	2.0	114.0	
Water level.....	12.0	104.0	
Bottom of pit.....	13.0	103.0	In gravel
<u>L-7</u>			
Surface.....	0.0	115.0	
Bottom of overburden	1.0	114.0	
Top of clay seam.....	4.0	111.0	Blue, sticky
Bottom of clay.....	5.0	110.0	
Water level.....	11.5	103.5	
Bottom of pit.....	12.5	102.5	In gravel

Table 5.- Field notes of test pits - Continued

<u>Test pit No.</u>	<u>Feet</u>	<u>Elevation</u>	<u>Remarks</u>
<u>L-12</u>			
Surface.....	0.0	111.5	
Bottom of overburden..	1.0	110.5	
Water level.....	10.0	101.5	
Bottom of pit.....	11.0	100.5	In gravel
<u>G-2</u>			
Surface.....	0.0	114.0	
Bottom of overburden..	1.0	113.0	
Water level.....	11.0	103.0	
Bottom of pit.....	12.0	102.0	In gravel
<u>G-7</u>			
Surface.....	0.0	113.0	
Bottom of overburden..	2.5	110.5	
Water level.....	10.0	103.0	
Bottom of pit.....	11.0	102.0	In gravel
<u>G-12</u>			
Surface.....	0.0	109.0	
Bottom of overburden..	2.5	106.5	
Water level.....	8.5	100.5	
Bottom of pit.....	9.0	100.0	In gravel
<u>B-2</u>			
Surface.....	0.0	111.0	
Bottom of overburden..	2.0	109.0	
Water level.....	10.0	101.0	
Bottom of pit.....	11.0	100.0	In gravel
<u>B-7</u>			
Surface.....	0.0	108.0	
Bottom of overburden..	2.0	106.0	
Water level.....	8.0	100.0	
Bottom of pit.....	9.0	99.0	In gravel
<u>B-12</u>			
This point in river and no pit sunk. Gravel in river bed at elevation 97.0			

In studying the findings of these test pits it will be noted at once that L-7 cut through a bed of clay 1 foot thick, and none was discovered in the other pits. It therefore became necessary to drill holes around G-7 in order to outline the clay bed. In order to check further it was decided to drill along the north and south lines 6 and 8. Holes L-6, J-6, G-6, D-6, and B-6 and similar holes on line 8 were drilled and their data recorded in the same form as for the test pits above. (See Table 6.)

The drilling of these holes indicated that others would be needed to outline the clay bed effectually. Therefore, holes were drilled as shown by "X" on Figure 12. The original holes in section D discovered an area of fine sand within the gravel, as shown in Table 6, holes D-7, D-8, and D-10. This necessitated drilling of other holes to delineate this sand, also marked "X" in Figure 12.

Table 6.- Field notes of drilled holes

Hole No.	Item	Feet	Elevation	Remarks
L-4	Surface		115.5	
	Bottom of overburden	2.0	113.5	
	Water level	11.5	104.0	
	Bottom of hole	12.5	103.0	Gravel
L-6	Surface		113.5	Creek bed 2 feet below
	Bottom of overburden	1.0	112.5	
	Water level	9.5	104.0	
	Bottom of hole	10.5	103.0	Gravel
L-8	Surface		116.0	
	Bottom of overburden	2.0	114.0	
	Top of clay	5.5	110.5	
	Bottom of clay	6.5	109.5	
	Water level	13.0	103.0	
	Bottom of hole	15.0	101.0	Gravel
L-10	Surface		113.5	
	Bottom of overburden	2.0	111.5	
	Water level	11.5	102.0	
	Bottom of hole	12.5	101.0	Gravel
J-2	Surface		115.0	
	Bottom of overburden	2.5	112.5	
	Water level	11.0	104.0	
	Bottom of hole	13.0	102.0	Gravel
J-4	Surface		114.5	
	Bottom of overburden	1.5	113.0	
	Water level	10.5	104.0	
	Bottom of hole	12.5	102.0	Gravel
J-6	Surface		114.5	Creek 2 feet below
	Bottom of overburden	0.5	114.0	
	Top of clay	4.0	110.5	Blue, sticky
	Bottom of clay	4.5	110.0	
	Water level	10.5	104.0	
	Bottom of hole	12.5	102.0	Gravel

Table 6.- Field notes of drilled holes - Continued

Hole No.	Item	Feet	Elevation	Remarks
J-7	Surface		116.0	
	Bottom of overburden	2.0	114.0	
	Top of clay	5.5	110.5	
	Bottom of clay	6.5	109.5	
	Water level	13.0	103.0	
	Bottom of hole	14.0	102.0	
J-8	Surface		115.0	
	Bottom of overburden	1.5	113.5	
	Top of clay	5.0	110.0	Blue, sticky
	Bottom of clay	6.0	109.0	
	Water level	12.0	103.0	
	Bottom of hole	13.0	102.0	Gravel
J-10	Surface		113.0	
	Bottom of overburden	1.5	111.5	
	Water level	11.0	102.0	
	Bottom of hole	12.0	101.0	Gravel
J-12	Surface		111.0	
	Bottom of overburden	2.5	108.5	
	Water level	10.5	100.5	
	Bottom of hole	11.5	99.5	Gravel
G-4	Surface		114.0	
	Bottom of overburden	2.0	112.0	
	Water level	11.0	103.0	
	Bottom of hole	12.0	102.0	Gravel
G-6	Surface		113.0	
	Bottom of overburden	2.0	111.0	Creek 2 feet below
	Water level	10.0	103.0	
	Bottom of hole	11.0	102.0	
G-8	Surface		113.0	
	Bottom of overburden	3.0	110.0	
	Water level	11.5	102.5	
	Bottom of hole	12.0	101.0	Gravel
G-10	Surface		111.5	
	Bottom of overburden	2.5	109.0	
	Water level	10.0	101.5	
	Bottom of hole	11.5	100.0	Gravel
D-2	Surface		113.0	
	Bottom of overburden	2.5	110.5	
	Water level	12.0	101.0	
	Bottom of hole	13.0	100.0	Gravel

Table 6.- Field notes of drilled holes - Continued

Hole No.	Item	Feet	Elevation	Remarks
D-4	Surface		112.0	
	Bottom of overburden	2.0	110.0	
	Water level	11.0	101.0	
	Bottom of hole	12.0	100.0	Gravel
D-6	Surface		111.0	
	Bottom of overburden	2.0	109.0	
	Water level	10.5	100.5	
	Bottom of hole	11.0	100.0	Gravel
D-7	Surface		111.0	
	Bottom of overburden	2.5	108.5	
	Water level	10.5	100.5	
	Bottom of hole	11.5	99.5	Sand
D-8	Surface		110.0	
	Bottom of overburden	2.5	107.5	
	Water level	10.0	100.0	
	Bottom of hole	11.0	99.0	Sand
D-10	Surface		106.0	
	Bottom of overburden	1.0	105.0	
	Water level	6.0	100.0	
	Bottom of hole	7.0	99.0	Sand
D-12	Surface		102.0	
	Bottom of overburden	1.0	101.0	
	Water level	2.0	100.0	
	Bottom of hole	3.0	99.0	Gravel
B-4	Surface		110.0	
	Bottom of overburden	2.0	108.0	
	Water level	9.5	100.5	
	Bottom of hole	10.0	100.0	Gravel
B-6	Surface		109.0	
	Bottom of overburden	2.0	107.0	
	Water level	8.5	100.5	
	Bottom of hole	9.5	99.5	Gravel
B-8	Surface		107.0	
	Bottom of overburden	2.0	105.0	
	Water level	7.0	100.0	
	Bottom of hole	8.0	99.0	Gravel
B-10	Surface		102.0	
	Bottom of overburden	0.5	101.5	
	Water level	2.0	100.0	
	Bottom of hole	3.0	99.0	Gravel

Having thus discovered two areas of change in character of material within the 40-acre boundary, it was decided to drill other holes to be sure of no further irregularities. Such holes having developed nothing new, the next step was to tabulate the data from the separate holes in groups representing the numbered and lettered lines from which to construct vertical sections.

These notes were tabulated in the same manner as the data from the test pits and are shown in Table 5. From the data in these tables sections were drawn as shown in Figures 7, 8, and 9.

From these sections there is obtained information as to the extent of the deposit except as to its depth. Since all test pits and drilled holes struck permanent water, the depth of the gravel must be determined by churn drill or bailer. Where a number of 40-acre tracts adjoin under the same ownership and the deposit is thick, one deep hole through the gravel on each 40 acres may be sufficient. However, if any two such holes differ considerably in the elevation of the bottom of the gravel others must be drilled to check that irregularity. In thin deposits more frequent depth checks must be made.

The samples taken from the test pits and supplemented by the borings from the holes give information from which an accurate estimate can be made of the gradation and value of the deposit.

In drawing the sections (figs. 7, 8, 9) the horizontal scale was taken as equaling 25 feet for each square and the vertical as 1 foot for each square. Thus, each square represents 25 square feet.

From these vertical sections (five drawn east and west and seven drawn north and south) calculations are made as to the quantities of material available.

Using the east-west sections first, the ground between section L and the north boundary is assumed as having a uniform vertical section equaling section L. Its volume will then equal the square feet in section L multiplied by the distance of that section to the boundary or 160 feet.

In computing the volume of that ground between sections L and J, the areas of the two sections are computed and their mean is multiplied by the distance between them.

By counting squares and multiplying by 25 the cross-sectional area of overburden, clay, or gravel can be obtained. By using mean sectional areas and the distance between them, volumes can be computed in cubic feet, which in turn can be converted to tons or cubic yards as desired.

The five east-west sections and the seven north-south sections can be computed separately as checks.

In making the computation the author assumed the overburden to weigh 90 pounds per cubic foot in place, clay the same, and sand and gravel to weigh 125 pounds.

The results of the computations are as follows in tons:

	<u>East-west</u>	<u>North-south</u>	
	<u>sections</u>	<u>sections</u>	<u>Average</u>
Overburden.....	125,918	128,593	127,255
Clay.....	3,978	3,971	3,975
Sand and gravel	805,937	797,961	801,949

Although the preceding method of computation is admittedly not mathematically exact, the author has found it to be sufficiently accurate for practical purposes.

In the exploration of this tract 87.5 feet of test pits were dug and 518 feet of holes drilled.

Assuming a cost of 20 cents per foot for drilling and \$1.50 per foot for test pits, the exploration cost would be \$234.85, or \$0.0003 per ton of sand and gravel above the water level.

The computation for sand and gravel below the water level is a simple multiplication of the horizontal area in square feet by the depth in feet ascertained by churn drilling. This will give the cubic feet of material which multiplied by 125 pounds per cubic foot and divided by 2,000 will give the amount in tons.

This example worked out in elementary detail illustrates the information which can be developed by proper exploration and computation of results.

SAMPLING

Sampling a deposit of sand and gravel is one of the most important functions of exploration. Singularly enough, it is given comparatively little thought by the average operator. All too often a small amount of the dump from each test pit is taken from the most convenient part of the pile and considered as representative of that pile. These portions are thrown together and subjected to careful and exacting screen analyses. The result is then considered as a screen analysis of the whole deposit. The author wishes to particularly emphasize this error, for he has found it to be very common in practice. The actual result of such a test is merely a screen analysis of the material used in the test.

Often operators are surprised and disgusted at the difference in the analyses of material submitted to two or more commercial testing laboratories. The testing laboratory can do nothing more than analyze the material submitted to it. If the samples themselves are unlike, the results from different laboratories are bound to differ. Therefore, in submitting two samples of the same material to different analysts, great care must be taken to assure that both truly represent that material. It is axiomatic that an analysis can be no more accurate than the sample. The care and accuracy of test methods too often far exceeds that used in sampling. It should be quite evident that precision in measurement and test weighing is useless unless equal precision is used in collecting the test sample so that it is truly representative of the material examined.

The following abstract from a definition of sampling is worthy of repetition:

The correct sampling of a lot of ore (material) is the process of obtaining from it a smaller quantity which contains unchanged percentages of all the constituents of that lot. As there are limits to the accuracy of weighing and determining the constituents it is necessary only that the error in sampling be smaller than the error in testing.¹⁶

The first step in obtaining a truly representative sample of a deposit is the systematic placing of drill holes and test pits over the entire area. Such procedure provides the opportunity for securing accurate samples.

The next step, equal in importance, is the method of taking the sample itself. In sampling test pits the object aimed at is a continuous sample from top to bottom. If the walls of the pit do not require timbering, collection of such a sample is simple. One sampler holds a box against the wall while another with pick or shovel cuts a vertical channel in the wall 6 inches to 1 foot wide, and 2 to 6 inches deep. Collection of material in this manner should be stopped at regular vertical intervals and a new box used. The sample taken should be carefully labeled with the number of the hole and the depths from and to which the

16 - Peele, Robert, Mining Engineers Handbook: John Wiley & Sons (Inc.), New York, 1918, p 1730

material was removed. Vertical intervals vary with different deposits. Where the gravel contains thin sand or clay beds the boxes should be changed at each change in material. Where the deposit is uniform, 5-foot intervals are sufficient. The sampler should keep a record in his notebook as to any unusual occurrence in the deposit such as single boulders or nests of boulders, water seams, changes in bedding, etc. His notes should also show from which wall of the pit the sample was taken. It is often advisable to take a similar sample from the opposite wall as a check.

Where the walls of a pit will not stand without timber, the sampling must be done as the pit is sunk. It is seldom that gravel pits will not stand in place for a vertical distance of 2 feet. In other words, it is seldom that the timber must be kept within 2 feet of the bottom. Usually 4 to 5 feet is ample protection. In such cases the wall channel samples are taken just prior to the placing of timber. The procedure is the same except that each 5 feet is sampled separately instead of sampling the whole depth at one time.

In such cases where timber must be kept close to the bottom or in advance of the digging, as in loose dry sand or quick sand, a different method must be employed. Such deposits are by nature more homogeneous in character, and vertical accuracy is not so essential except for notation of the depth at which radical changes occur. In such cases it is often sufficient to take a channel sample across the floor of the pit at each vertical foot in depth.

Sampling by earth augers is of course automatic. The material removed by the auger should be placed in line on the surface. It is then bagged in the predetermined vertical intervals, tagged, and recorded in the sampler's notes.

Sampling of material obtained by bailer or churn drill or wherever water is used or encountered in the hole presents other difficulties in obtaining accuracy. Accurate samples are obtainable by churn drill or bailer only where it is possible to drive the casing ahead of the drill bit or sand pump. Where the bit precedes the casing, contamination is always present from material falling in from the walls of the hole. The presence of water tends to segregate fine sands and clay from coarser material.

These fine materials are maintained in suspension by the churning action of the drill or bailer. Accurate sampling requires that for each vertical interval cut by the drill all material be saved whether coarse or fine. This means that the material in suspension must be saved along with the coarse material. In order to accomplish this, the simplest procedure is to drive the casing 2 feet ahead of the bit or bailer, add the necessary water and drill or bail to the bottom of the casing. All material, including the water, as removed from the hole, should be placed in a box from which no water is allowed to escape before the fines settle out. When completely settled the clear water is poured off and the material in the box bagged and labeled for hole number and depth as before.

When using the small clamshell bucket within casing, the pipe should be driven ahead of the digging a predetermined distance, and the coarse material removed and placed in a continuous pile or ridge. When the bucket has dug to the bottom of the pipe, the water and suspended material should be removed by a bailer and allowed to settle. This fine material is then added to the coarser material and thoroughly mixed before bagging the sample.

When drilling below water level, it is difficult to obtain accurate samples of both fine and coarse material because water enters from the bottom of the casing. This entering water may bring with it fine material from surrounding areas beyond the casing. At best, it provides an excess of water which so dilutes the suspended material that it is almost impossible to obtain the fine and the coarse material from the same vertical section. Many times the incoming water enters so fast that it is impossible to bail the hole dry. This greatly dilutes the fine material and much of it is consequently lost. Therefore, samples taken below the water line must be considered to have been subjected to loss of fines.

When holes encounter boulders and it is impossible to drive casing, they should be stopped and a new hole started as close to it as possible, or the boulder blasted. In deposits containing many loose or clustered boulders, drilling holes may be more expensive than test pitting because of this loss of holes and consequent extra work.

Requirements for extra holes can be determined from the sampler's notes. As an example, holes M-7, M-8, M-9, L-9, K-6, K-9, and J-9 on Figure 12 were drilled to outline the clay seam as shown in dotted lines. Also holes D-7, D-8, and D-10, having shown sand in the bottom, extra holes were drilled at E-7, E-8, E-9, E-10, D-9, and C-7, C-8, C-9, and C-10, to make sure there was no extension of this fine-sand area.

Testing Samples

Comprehensive tests on samples collected by exploration can be made only in a properly equipped laboratory by trained personnel. Few operators are so equipped at their plants. Consequently final testing is usually a matter for the commercial laboratory. However, it is not the function of this paper to describe in detail the exact test methods of the laboratory.

The object of exploration is a rough determination of the size, shape, and value of a deposit. The size and shape have been determined by test pits and holes. The value may be roughly determined by various field tests of the samples. Should these field tests indicate that the deposit has commercial possibilities, then similar samples should be subjected to exhaustive laboratory tests. In only a few instances will it be necessary to have final tests made before a decision can be reached as to the commercial possibilities of the deposit. In such cases a visual inspection of the samples will reveal an appreciable amount of deleterious materials, thus at once placing the deposit on the border line between a paying or losing business. Accurate testing then becomes necessary to determine whether the deleterious matter can be removed profitably and the type of equipment that will be required.

Preliminary or exploration testing will be confined to such items as:

1. The specific gravity.
2. Absorption.
3. The percentage of organic impurities present.
4. The percentage of clay and silt present.
5. The size gradation of sands and gravels.
6. The percentage of soft, friable, and unsound particles present.
7. The presence or absence of deleterious coatings.

The following field tests are suggested for exploration testing, and corresponding laboratory tests as recommended by the American Society for Testing Materials are cited.

Specific Gravity Tests

The true specific gravity of a substance is equal to its weight dry, divided by the weight of an equal volume of distilled water at 4° C. (39.2° F.).

All mineral substances in their natural state contain both open and closed pores. These must be eliminated to determine the true specific gravity. To do this the sample is ground to pass 200-mesh before making the determination.

True specific gravity is seldom used, however, in connection with sand and gravel determinations. The term commonly used is "apparent specific gravity."

The apparent specific gravity of a substance is equal to its weight in air divided by the difference between its weight in air and in water.

Let W_a = the weight of the sample in air.

W_w = the weight of the sample suspended in water.

Then the apparent specific gravity =
$$\frac{W_a}{W_a - W_w}$$

The apparent specific gravity may be determined in the field by first carefully weighing a sample of the material in air and then submerging the sample and container in water and weighing again.

Some particles of sand and gravel are much more porous than others. Material submerged in water absorbs water at varying rates, depending on its porosity. Therefore the observed weight submerged must be read instantaneously upon submergence and before absorption occurs, otherwise a potential error is introduced. This potential error has led to a modified practice in this test. The sample to be tested is weighed in air after drying at room temperature and the weight recorded as W_{da} . It is then placed in water and allowed to stand 24 hours, or until saturated. The sample is then surface dried and weighed and this weight recorded as W_{sa} . It is then submerged in water, weighed and the weight recorded as W_{sw} . The apparent specific gravity of the saturated sample is then

$$\frac{W_{da}}{W_{sa} - W_{sw}}$$

Absorption

For a more accurate laboratory method see A.S.T.M. designation C-68 and D-55 for sand and C-86 and D-30 for gravel.

The absorption test is performed in determining the specific gravity. $W_{sa} - W_{da}$ equals the absorption.

Organic Impurities

Organic impurities, such as leaves, twigs, peat, and coal, can be eliminated by burning. As low as 0.05 per cent of certain organic impurities if contained in aggregates are injurious to concrete.¹⁷ On the other hand, appreciably greater amounts of other organic impurities such as lignite are permissible.¹⁸

A common test for organic impurities consisted in recording the weight of the sample in air when dried at less than 110° F. to constant weight. The sample is then heated to 400° to 500° F. for about one half hour, cooled, and again weighed. The difference in weight was recorded as the loss in organic matter.

However, small amounts of impurities would present such small losses by this method as to require precision balances to detect them. Since these balances are not available in the field the colorimeter test should be made as follows.¹⁹

Fill a 12-ounce graduated prescription bottle to the 4½-ounce mark with the sand sample. Add a 3 per cent solution of sodium hydroxide to the 7-ounce mark. Shake thoroughly and let

17 - Abrams, Duff A., Effect of Tannic Acid on the Strength of Concrete: Struct. Mat. Research Lab., Lewis Inst., Chicago, Bull. 7, 1922, p. 27.

18 - American Society for Testing Materials, Effect of Coal and Lignite in Sand for Concrete: Proceedings, 1929, pt. 1, p. 328.

19 - American Society for Testing Materials, Standards, pt. 2, 1930, p. 154.

stand 24 hours. Observe the color of the clear liquid above the sand. Clear or light yellowish color indicates sand satisfactory for concrete so far as organic impurities are concerned. Straw color indicates sand suitable for unimportant concrete. Dark colors indicate sand unfit for concrete.

Sand showing straw or dark color should be examined for lignite. If present, the sand should not be condemned on account of the colorimeter test until it is confirmed by mortar strength tests.

The more accurate method for determining the percentage of organic matter present is described under A.S.T.M. designation C-40.

Clay and Silt

In determining the amount of clay and silt present, record the weight of the sample as dried in air to constant weight, as W_d . Place the sample in a suitable pan in which it can be covered with water. Stir thoroughly and pour off the water, being careful that no sand is poured off. Add more water, stir, and pour off. Repeat until the water removed is clear. Dry the remaining sample to constant weight and weigh. Record this weight as W_c .

$W_d - W_c$ = weight of clay and silt removed.

$W_d - W_a$

----- x 100 = per cent of clay and silt.

W_a

A similar method is followed by some operators and has the advantage of using larger samples, thus avoiding possible errors in sample reduction.

A small revolving screen (3/8-inch mesh) is mounted in a water-tight wooden or metal box. The box is partly filled with water so that the material in the screen is submerged. The sample is then placed in the screen and revolved. The material retained in the screen will be gravel and that passing through to the box will be sand, clay, and silt. The latter is allowed to settle and the water drained off. The sand, clay, and silt are then subjected to the clay-silt test as previously described.

This test has the advantage of showing the character of the clay and its effect in adhering to gravel, collecting fines, accumulating as balls, etc., under conditions simulating plant practice.

The A.S.T.M. tests for determination of clay and silt in fine and coarse aggregates is termed the "decantation test" and may be found under the designation D-136 for sand and D-72 for gravel.

Size Gradation

The field sample is now ready for a sieve analysis. The first step in the field test is a separation of the sand from the gravel.

The dried sample from the clay and silt determination is weighed and the weight recorded as A.

The sample is then placed on a screen perforated with 3/8-inch round holes and agitated to refusal - i.e., till no material will pass.

The material passing the screen is weighed and the weight recorded as S. The material retained is weighed and recorded as G.

Then $S + G = A$

and $S/A \times 100$ = per cent of sand.

$G/A \times 100$ = per cent of gravel.

Sample S is then sieved through the testing sieves for sizing. Various sets of sieve standards have been and are being used. For the purpose of uniformity it is recommended that the A.S.T.M. sieve standards as given under designations E-11 and E-17 be used.

When so used the sand sample of weight S will be sieved over and through sieves Nos. 4, 8, 16, 30, 50, and 100. The weight of the material passing each will be recorded in tabular form as follows:

<u>Passing</u>	<u>Retained on</u>	<u>Weight</u>
3/8	4	t
4	8	u
8	16	v
16	30	w
30	50	x
50	100	y
100		<u>z</u>
Total = S =		(S)

Then $\frac{t}{S} \times 100$ = per cent passing 3/8 inch and retained on No. 4 sieve, etc.

A

Sample G will then be passed through screens having the following sizes of round perforations: 3 inch, 2 inch, 1-1/2 inch, 1 inch, 3/4 inch, 1/2 inch. The weight of the material passing each and retained on the next smaller opening will be recorded in tabular form as follows:

<u>Passing, inch</u>	<u>Retained on, inch</u>	<u>Weight</u>
3	2	o
2	1-1/2	p
1-1/2	1	q
1	3/4	r
3/4	1/2	s
1/2	1/4	<u>t</u>
Total = G =		G

Then $\frac{o}{G} \times 100$ = per cent passing 3-inch and retained on 2-inch, etc.

A

Local conditions may require the use of sieves and screens with openings of other than the sizes shown, but the procedure for testing will be the same in any case.

For A.S.T.M. standard methods see designations C-41, D-7, and D-19.

The major questions which arise in the mind of the operator in valuing a sand and gravel deposit after it has been demonstrated that sufficient volume is present are -

1. The percentage of sand present.
2. The percentage of fines that must be removed from the sand to make it marketable.
3. The percentage of fine gravel that must be wasted.
4. The percentage of gravel present.
5. The percentage of oversize that will require crushing.

With properly collected samples the preceding sieve tests will provide the proper answers to these questions.

Soft, Friable, and Unsound Particles

This test applies to the gravel only and is made by what are known as the soundness and abrasion tests. Both of these tests require laboratory apparatus for accuracy. However, the experienced prospector will be able to appraise closely the percentage of soft, friable, and unsound particles present by a visual inspection, for which a portion of the sample is spread on a table and the deleterious particles separated and counted. This count compared to the total number of particles gives the percentage.

The sodium sulphate test is commonly used for a soundness test of material showing no soft particles on visual inspection. This test can be made in the field as follows.

A saturated solution of sodium sulphate is prepared. It is important that this solution be saturated and kept in this condition. The gravel sample is then placed in this solution and allowed to stand for 18 to 24 hours. It is then removed, oven dried, and again immersed in the saturated solution for another 18 to 24 hours. This alternate soaking and drying is repeated five times. The test should be carried on in a warm room. This field test will expose unsound material and because of the range of temperature changes will be somewhat more severe than the laboratory test.

The A.S.T.M. designation for laboratory soundness test is C88-31-T and C89-31-T.

Any preliminary test of new gravel deposits should include a laboratory test.

Deleterious Coatings

Gravel particles are often coated with deleterious siliceous, calcareous, or argillaceous materials which if not removed cause unsound concrete. There is no particular test for these coatings other than visual inspection of the washed sample. The apparatus mentioned under the clay and silt test, page 36, will be valuable in facilitating inspection of the gravel under conditions simulating actual plant washing practice.

In addition to the preceding tests the material should be tested for abrasion loss. There is no practical field test for this and it must be performed in a laboratory having the proper equipment.

The A.S.T.M. designation for abrasion test is D289-28T.

Splitting Samples

Often it is desired to split the sample to have it tested by independent laboratories. In doing this exceeding care must be taken, or erratic results will follow. Here is where many operators have difficulty.

Sand or fine gravel samples can be split without much danger of discrepancy, but as the material increases in size the difficulty of accurate cutting increases proportionately.

A method commonly used is the cone and quarter method. This is employed extensively in metallurgical plants and is more or less standardized. Sand and gravel operators have adopted it in many cases without inquiring as to whether it was adapted to their material or not. As a matter of fact, it is not. The cone and quarter method is applicable only to material that has been previously screened to approximately the same size. With a mixture of sand and gravel, conditions are changed and the method is not accurate.

In the cone and quarter method, the sample is spread out on a metal or wooden floor in a rough circular pile a few inches thick. The sampler then takes a small shovel and throws material from the periphery of the pile to the center, letting each shovelful fall on the cone which is thus built up. After thorough mixing in this manner, the operator divides the cone into four quarters either with his shovel or by inserting a plate vertically through

the pile in one direction and separating the two halves. The plate is then turned at right angles and the two piles separated into four, or quarters. Each quarter then is supposed to represent accurately the whole original sample. This works well with sized material but where coarse and fine particles are indiscriminately mixed in a sample, the coarser lumps roll to the outer edge of the cone and the fine remain in the center. This size segregation prevents accuracy in quartering for it is impossible to assure equal rolling in all directions from the top of the cone.

Better results are obtained in splitting samples of mixed sizes by the use of automatic samplers. These are boxes in which partitions are placed whereby material falling within one section will be diverted to one direction while material in the next space will pass to another direction. In their use the sample is shoveled onto the sampler which automatically separates it into two representative portions.

Figure 13 illustrates a simple device for this purpose. Obviously, the width between partitions must be greater than the largest particles in the sample.

The deposit having been discovered by the prospector and properly examined by exploration and testing, the work of the prospector ceases. It now devolves upon the operator to evaluate the results obtained from the prospector's tests with the market requirements, to ascertain whether the deposit has an economic value. If there is an excess of fine sand, or fine gravel, he must ascertain how great this excess will be from his screen analysis of the samples. This will show him how much material must be wasted or what markets he must investigate for its disposal. From the same analyses he can determine the size of his treatment units for a given capacity requirement, and thus construct a flow sheet for the proposed plant. Thus prospecting and exploration are, or should be, the foundation upon which the operator bases the value of his deposit as well as the location and design of his plant.

APPLICATION OF PROSPECTING AND EXPLORATION METHODS TO VARIOUS TYPES OF DEPOSITS

Residual

This type of deposit results from the weathering of bedrock in place. No transportation has taken place and the sand and gravel is usually intimately intermixed with clay and boulders.

Prospecting methods, in addition to a study of local geology, will involve an examination of the physical character of fragments exposed on the surface. Search will be limited to the tops of well-rounded ridges having thick, heavy subsoil and lying between well-defined drainage basins. Favorable areas are those portions of the country underlain by limestone or other decomposable rock and which have not been overrun by glaciers.

Since residual deposits are seldom over a few feet thick, exploration will consist of shallow test pits and boreholes sunk either by auger or churn drill. Many holes will be lost because of encountering boulders, and particular care must be exercised in determining the percentage and character of fine sand and clay present. Careful examination and testing of the commercial sand and gravel will be necessary because of the presence of "rotten" or badly weathered stone which will not stand up under hardness and abrasion tests. Because of the usual high percentage of flint or chert particles, care must be given to see that they pass engineer's specifications for concrete aggregate. Residual deposits are not as a rule favorable for commercial development, and when exploitation of them is contemplated unusual care is needed both to ascertain their physical composition and to design the proper type of plant that will eliminate the impurities and assure a market material that will pass specifications.

Fluvial Deposits

Fluvial deposits vary considerably in type and will require different methods both of prospecting and exploration. Land deposits may be classified into:

Alluvial cones and plains,
River terraces and flood plains, and
Deltas.

The method of formation of these several types has been discussed previously in this report.

Alluvial cones are recognizable from their proximity to mountain ranges and the character and distribution of the particles. Alluvial sands are usually not well rounded, but fairly angular. They will contain few pieces of decomposable minerals such as limestone, feldspar, etc. Gravels, on the other hand, will be subangular to well rounded with smooth surfaces, and if transported only short distances may contain small to large percentages of decomposable minerals. Deposits will contain comparatively small amounts of fine sand and clay, but the coarser sand, gravel, and boulders may be more or less segregated in irregular lenses. Clusters of boulders may also be present near the base of the cone. Alluvial cones will range from a few feet to several hundred feet in vertical thickness.

Prospecting for this type of deposit will involve principally a study of local geology and topography.

Exploration will involve test pits and churn or other types of drill holes. Augers will be useless except in determining the depth of overburden.

In large cones approaching alluvial plains in size, the search will be directed to ascertaining that portion of the deposit which contains the best commercial gradation. Nests of boulders are not objectionable, but they will require crushing machinery. Test pits supplemented by churn drilling will probably be the best methods to use. It will seldom be necessary to ascertain the depth of large cones because of their great thickness and extent.

Ordinarily there will be less need for determining the percentage of fine sand and clay because of their limited presence due to the manner of formation. When present, they will be in such form as will require a comparatively minor treatment for elimination. Soft or rotten stone will not usually be present. Careful testing of pit and drill-hole samples will be necessary, however, to ascertain the percentage of gradation present, in order that the pit and plant may be located on the most favorable portion of the deposit. Careful testing may develop areas wherein sand may be produced separately from gravel. Usually such deposits will be well drained and there will be no water remaining in drill holes. Depth drilling will be necessary only to determine the commercial quantity available.

Alluvial plains are similar to cones where they abut steep mountain ranges, and prospecting and exploration methods are the same as for cones. Where they extend great distances from the mountains, as in the great plains area, the deposits will not attain such great thickness and the ingredients will be better graded with fewer boulders and more fine sands. There will be more clay intermixed with the material also, as the distance from the mountains increases until finally alluvial plains merge into flood plains.

In prospecting, a knowledge of the local geology will be of considerable help in locating ancient river courses. In extended plains, local topography will not help greatly, but vegetation may indicate deposits. The prospector will do well to be guided by exposures in river banks, railway, and highway cuts and in well records.

Exploration will be best accomplished by test pits supplemented by drilled holes. The churn drill will be useful because some deposits will be found to extend below the subsurface

water level. Augers may be used in determining overburden depth and occasionally in obtaining sand or gravel samples. The casing and bailer method may also be found to be advantageous.

Care must be exercised in testing for clay and fine sand content as well as the percentage of fine gravel. All gravel must be carefully tested for hardness and abrasion. The same scrutiny must be made for gradation also. Since this type of deposit varies greatly in thickness, occasional holes or pits must be sunk completely through the deposit to be sure of its depth. The subsurface water level must be accurately determined, since the entire method of exploitation may depend upon the extent of the deposit below water.

River Terraces

Old rivers left considerable quantities of sand and gravel in their beds and banks. As continental elevations took place, or the river cut deeper in its bed, these deposits are left as terraces along the valley walls parallel to the stream. In such areas topography will be the principal guide for the prospector. Exposures in the river banks and along tributaries indicate deposits above, where terraced topography is present.

Observation should be made for the usual physical characteristics of the particles of fluvial deposits namely, angular sands and subangular to rounded smooth-faced gravels.

Exploration will employ test pits and the several types of drilling. Deposits will not usually reach great thickness and therefore their depth must be ascertained. Size segregation may be prevalent, hence exploration will seek to determine the gradation of the material. Abrupt changes in gradation may occur, therefore drill holes or pits may show erratic results over short distances. Many extra holes will be needed to interpret these discrepancies. As such places are usually well drained, permanent water will seldom be found in holes in terrace deposits. Occasional silt or clay beds will require careful testing as to the percentage of such material or the outlining of such beds by drilling so that they may be avoided in later exploitation. Auger holes may be used to advantage in testing overburden and outlining area and thickness of surface sand or clay.

Flood Plains

Flood-plain deposits are formed by the material carried over the river banks during periods of high water. Each single deposit is necessarily thin but where a river periodically overflows the same area these may be built up to considerable thickness.

Regional topography will be the principal guide to the prospector in his search for this type of deposit. His search for commercial material will be materially assisted by records of wells and cellar excavations as well as by exposures in railway and highway cuts, dry gulches, and banks of tributary streams. They are usually covered by soil of varying depths and the deposits themselves are likely to be badly intermixed with beds of clay or silt. Gradation is generally erratic and particular care must be taken to determine the percentages of clay, silt, fine sand, and commercial sand and gravel present. Usually there will be a much higher percentage of sand and fine materials than of coarse gravel in flood-plain deposits. The bars in rivers traversing flood plains will be found to be badly contaminated with silt also.

Test pits and all types of drilling are the methods employed for exploration. Holes must be spaced at shorter intervals because of the sudden and erratic changes in the ingredients. Ordinarily flood-plain deposits are above subsurface water levels, but in some cases they are not. Therefore, it is important to determine the permanent water level. Great care must be used in ascertaining not only the percentages of fine and coarse materials present,

but the gradation of commercial sizes. Since the deposits are usually thin, their depth must be investigated. Flood-plain deposits rarely contain clean sand nor do they contain sands in commercial gradations. This means that equipment must be installed to eliminate the undesirable sizes; hence, it is important to know beforehand the percentage proportion they represent.

Commercial sand and gravel in such deposits, however, will usually be quite free from soft particles in the form of rotten stone or decomposable material. The problem to be solved by exploration is one of extent and gradation in order that a commercial material may be made from a noncommercial natural deposit.

Delta Deposits

Deltas are formed in the ocean or lakes at the mouths of rivers. Usually before reaching the sea or lake the river current has so lost its velocity as to render it incapable of transporting material coarser than fine sand. Therefore, delta deposits are usually deficient in commercial gravel. However, during flood periods the velocity may be so increased as to allow it to bring down and deposit coarse material. Also, where the debouching river meets strong wave or tidal action the fine material may be caused to remain in suspension by agitation until carried far beyond the mouth, and only the coarser product be deposited in the delta. Thus considerable sorting is possible.

Prospecting on deltas is simple in that it is confined to relatively small areas bounded by the extreme migration of the river and the sea or lake. Old abandoned river courses may present outcrops in their banks. Any artificial excavation will present material for study also.

Exploration will be by means of auger or drill hole, since the proximity of the permanent water level to the surface prevents the use of test pits.

Because of the multiplicity of materials deposited and the changing course of the river, extreme care must be used in exploration to determine both the kind of material, its size gradation, percentage composition, the presence of soft or inferior particles, and the presence of debris.

River Bars

Underwater fluvial deposits are found within the banks of rivers or streams. They form shifting bars built by the water currents. The river may cut away a bank at one point and deposit the material in a bar at another, which in turn may be cut at a later date and deposited still lower in the course of the stream. Under favorable conditions a river may break through its bank and abandon the old stream bed entirely.

Nearly all river-bar deposits are visible at one season or another. In some rivers irrigation or navigation dams have raised the water level and covered previously exposed bars but where such artificial barriers have not been erected shifting currents will usually expose deposits at some time. This makes prospecting fairly simple. Since running water sorts and grades materials, coarse sands and gravels will be expected in the swifter currents and as the velocity decreases the size of particles also decreases.

Any agency which causes a deflection of the stream course or decrease in velocity of its current also causes deposition. Thus sand and gravel deposits may be expected in bars on the inner sides of bends. A tributary entering a river from one side tends to divert or retard its current, and deposits may be expected on the up-river side of the mouths of tributaries. Shoal places in the river below deep channels tend to retard the current and material is deposited above them. The prospector must depend upon his knowledge of, or information he can

obtain concerning, the habits of the river currents, both as to present and past history, for likely sites in locating river bars. Where the gravel is not exposed to view the prospector may use a long steel bar and sound for gravel in the river bed. Usually, however, prospecting for river-bar gravels is done by dredging. The dredge is spotted at a likely site and digs from the bed until it can be determined whether the material is commercial or not.

Test pits in river bars are useless as they can not be extended below water level. Bar gravels, however, are ordinarily very loose and can at times be recovered by augers or drills within casing. The small orange-peel bucket operating within a casing should be helpful. as should also the bailer and casing.

Either of these methods promise success when they can be located on the bar where it outcrops above water level. For underwater work, however, they are not so successful because of the difficulty of holding casing steady from a boat on the surface. This does not mean that it can not be done, but the cost of such equipment together with the difficulties encountered increase the exploration expense until most operators prefer first to sound by bar and then spot the dredge.

Exploration of bars should develop the presence or absence of river debris such as sunken logs, tree trunks, waste materials from up-river sources, and strata of silt or fine sand. In some cases an abundance of shells may impoverish an otherwise commercial deposit or so alter conditions as to require special machinery for their elimination in the treatment plant

Since any exploration must be below water level, experience is necessary in collecting samples because of the danger of misinterpretation due to the partial removal of silt and fine sand by the water while in the act of collecting the sample. Care must be taken to see that there is not too much clay or silt present. As an example, one river deposit is reported as having several feet of good material in two beds between which lies a bed of heavy blue clay. Dredging the clay with the gravel so mixes the material that it is impossible to obtain a clean sand or gravel. Other types of clay cause little trouble and are easily washed out. Therefore, if clay is encountered, it should be carefully investigated as to its character and probable effect on the finished product.

There need be less care taken in determining the gradation of the material from river bars because in the recovery by dredging excess quantities of certain sizes may usually be wasted overboard without additional disposal cost. There is a need for information as to the approximate gradation, however, in order that the proper equipment may be installed for eliminating the waste sizes.

Care should be exercised in determining the amount of foreign industrial waste occurring in the deposit. As an example, in some river deposits considerable quantities of coal are encountered, resulting from refuse from up-stream coal-mine waste. This coal must be removed from the sand and gravel, and when it is present in sufficient amount may present a serious problem calling for special equipment. Also the amount of sunken debris present may determine the type of dredge necessary. Exploration in river beds which have been previously dug over for their gravel content encounters another type of difficulty. Dug-over river bottoms are often left in a series of inverted cone-shaped depressions. These provide excellent catch basins for all sorts of refuse brought down the river. They may also be found to collect boulders in nests from the sides of the cones or rolled along the bed of the river in flood periods.

River beds and bars are seldom over 50 feet thick; hence, it is essential that the thickness be determined both in order to calculate the tonnage available and to indicate the type of equipment necessary.

Marine and Lake Deposits

In searching for sand and gravel deposits in the coastal plain areas the prospector will need a knowledge of geology as well as topography. He will recognize deposits of marine origin both by the shape and position of the deposit as well as the physical characteristics of the particles.

Marine gravels found on the tops of well-rounded hills or ridges will differ from residual deposits in like topography in that they will be well graded and the particles usually well rounded. Few angular sands will be found and none of soft materials. Gravels will be well rounded with smooth faces having a dull polish, while residual gravels are rough and usually have pitted faces.

Likely sources will be terraces parallel to the seashore and flat-topped elevations between well-established drainage areas within coastal plains. Scrutiny should be given to stream banks cut through low hills or terraces, and railway and highway cuts. Vegetation may be a helpful guide also. The prospector operating in coastal-plain areas may encounter terraces parallel to seashores having materials which do not show marine characteristics. This is true along the Atlantic coast where some of the terraces are alluvial plains which have been washed and eroded from old shore lines. He should also not overlook river bars in coastal plains.

Regional topography and geology will be his principal guides. Observations should include inspection of exposures in stream banks cutting through terraces, as well as artificial excavations of all sorts.

Exploration will employ test pits and all classes of drill holes. The objective sought will be particularly to locate such portions of the terraces or hilltops as contain as near the proper-sized gradations as possible. Marine deposition tends to group gravels in fairly well-sorted sizes; therefore, fine sands may be found in one place and coarser material or boulders in another near-by. Often the commercial materials will be found overlaid by heavy silt or clay, the thickness and character of which must be carefully determined for its effect on later operation. There will be little difficulty with permanent water in the higher terraces, although this becomes a problem in more recent uplifts that are raised only slightly above sea level. Little trouble will be experienced with soft particles because of the long-continued abrasion both during transportation to its undersea location and later by wave action on beaches to which the material has been subjected. However, some marine gravels do contain limestone particles which have been formed in the sea by chemical means or as the result of organic remains. These usually will have been so worn by wave action as to lose their soft portions.

Of equal importance in marine deposition are the large offshore deposits along the continental shelf. These are similar to terrace deposits except that they have not been raised above sea level. They are formed by the deposition of material brought down by rivers and streams and are therefore of fluvial origin. Suspension in the heavy sea water is more potent than in fresh water and this combined with agitation from wave, tidal, and current action tends to carry finer silts and clays beyond the continental shelf into deep-sea levels. The sands and gravels are thus deposited close to shore on the continental shelf and form important sources of commercial material.

Prospecting for such deposits consists of examination of the adjacent beaches and the formation of offshore islands. Any approved method of making undersea soundings may be employed also. Probably the most often-used method is the actual digging of the material with dredges as is done in river-bar deposits.

Exploration is by dredge alone. The principal information sought is the depth below water surface and thickness and character of the material. This combination determines the

type of equipment necessary for exploitation. The habit of local tides is also a contributing factor in this problem, for material accessible at low tide may be out of reach if the tide variation is great. Harbor protection is also important, as dredging equipment is not ordinarily designed to withstand stormy seas.

Size gradation is important because of the tendency of wave action to sort material in size groups. Abundance of shell or coral formation may complicate production of commercial material. Therefore the percentage of these materials should be carefully ascertained by adequate exploration before production on a large scale is started.

Similar methods are employed in prospecting for gravels along the boundaries of inland lakes.

Occasional remnants of gravel deposits of marine origin are found far inland marking the shore lines of ancient seas. These are commercially unimportant as a class, however, inasmuch as more recent erosion has so reworked them that they are at present classed as fluvial. Deposits along the old boundary of the great Salt Lake are exceptions. These resemble alluvial fans or narrow plains in that they abut steep mountain ranges. Exposures in recent stream beds form the principal methods of examination for the prospector. Exploration methods are similar to those used in coastal plain terraces.

Glacial Deposits

It is essential that the prospector working in areas within the boundary of glacial action have a knowledge of the geologic history of the region. With such knowledge his understanding and interpretation of the various forms of deposit encountered will be greatly facilitated. This involves a knowledge of the origin of the formations and the resulting topography.

In his search the prospector will observe the position and appearance of isolated hills and ridges, the abundance of small lakes, the presence or absence of sharp topographic relief and the markings left on the surface of outcrops of bedrock. Grooves and striations on outcrops show the direction of ice movement. The relation of the long axis of ridges or the alignment of isolated low hills will indicate whether the deposits are moraines or eskers. This in turn will indicate to him the type of material he may expect below the land surface. Examination of particles where exposed in natural or artificial cuts will indicate glacial source by the striated or grooved surfaces of the gravels.

Sands containing particles of feldspar and other decomposable minerals indicate transportation over comparatively short distances or possible source in glacial deposits.

Sounding bars may be used to advantage through thin overburden to detect gravel below, although the prospector's principal reliance will be upon the topography and his knowledge of the geology of the region supplemented by examination of natural or artificial cuts and excavations.

Exploration will be by test pits, drill holes, and soundings. The latter, while of principal interest in prospecting, may be useful in outlining deposits under thin overburden. For the same purpose, auger holes are employed, although much difficulty may be expected from loss of holes through encountering boulders. The same difficulty will arise in the use of casing with drilled holes. Therefore, accurate sampling will necessitate the digging of frequent test pits.

Especially care must be taken in examining glacial deposits to determine accurately the proportion of fine sand and clay. Moraines especially are heterogeneous deposits of unsized materials which necessitate careful systematic examination because in the absence of bedding or segregation of any sort no assumptions can be made from superficial or cursory exploration. Such deposits must be tested over their whole area and throughout their full depth. This means that vertical examination is of equal importance with lateral examination.

The possibility of the material containing decomposable minerals which would be harmful in concrete construction must also be carefully ascertained. When discovered, their character and percentage must be determined as accurately as possible. This type of impurity may be found both as fine sand and coarse gravel or even boulders.

The gradation is important, not only for its relation to market requirements but to determine the proportion of boulders present that may require a crushing plant. This is not easy in this type of deposit because of the heterogenous mixture. Even with elaborate systematic exploration, considerable latitude in interpretation of results will be necessary. This must be tempered by the judgement and experience of the prospector.

Fluvioglacial Deposits

Fluvioglacial deposits resemble fluvial deposits in their formation. They differ in that they are found in close proximity to glacial deposits or the boundary of glaciated areas. Material contained in them will show an absence of clay and fine sand and considerable grading will be apparent. Sands will be angular but gravels will be rounded and smooth-faced. Less quantities of decomposable material will be present.

Outwash cones or plains will resemble alluvial cones and plains except that they will not abut mountain ranges. They will, however, emerge from old glacial moraines. Lateral and ground moraines will have been reworked and the material deposited in river bars or terraces along the course of the glacial streams or carried on to form outwash plains. Therefore, a knowledge of local and regional geology and topography is helpful.

Prospecting methods will be of the same type as for similar fluvial formations.

Fluvioglacial deposits will contain material showing the characteristic striations and grooves of glacial abrasion.

Exploration should develop the size and depth of deposits, the gradation of the materials, and the percentage of fines. The presence and character of decomposable material should also be determined. There will be ordinarily little clay present and materials will be fairly well graded even to size segregations to some extent. Vertical depth may range from a few feet to over a hundred feet; hence, depth must be determined.

TYPICAL EXAMPLES WITH COSTS

The United States Bureau of Mines has published a number of Information Circulars on sand and gravel mining methods and costs, of which the following table lists a few.

Typical examples of sand and gravel operations

<u>Publication No.</u>	<u>Company</u>	<u>Location</u>	<u>Type of deposit</u>
I. C. 6420	Menantico Sand & Gravel Co.	New Jersey	Marine
I. C. 6421	Ohio River Sand Co.	Kentucky	River bar
I. C. 6537	East Texas Gravel Co.	Texas	Flood plain
I. C. 6580	Ward Sand & Gravel Co.	Michigan	(Fluvioglacial Moraine)
I. C. 6581	Dallas Washed & Screened Gravel Co.	Texas	Fluvial
I. C. 6582	J. K. Davison & Bro.	Pennsylvania	River bar
I. C. 6592	Seaboard Sand & Gravel Co.	New York	Moraine
I. C. 6607	Consolidated Rock Products Co.	California	Alluvial fan

I. C. 6420

The deposits on the property of the Menantico Sand & Gravel Co. consist of two types. The older or Highland deposit is probably typically marine with little or no overburden and supporting a weak growth of scrub oak and pine. The Lowland deposits are found along stream courses and represent marine materials reworked and left as fluvial deposits.

Exploration was carried on by means of test pits limited in depth by the permanent water level. Below this depth hand-drilled test holes were put down on the corners of 100-foot squares at a contract price of \$1.50 per foot. Because of insufficient information obtained by this method, the clamshell bucket working within a 12-inch casing was adopted. This is now used to the water level. Below that a 4-inch pipe is sunk and a 3-inch pipe bailer is operated within it to remove the sample. The lower end of the pipe is filed to a rough cutting edge, and a flap valve is placed about 3 inches above. By churning the bailer up and down by hand the material within the 4-inch casing is loosened and brought to the surface.

Three men are used to operate the bailer. They average about 50 feet of hole per day at a cost of 30 cents per foot of hole.

I. C. 6421

The Ohio River Sand Co. operates wholly in river-bar deposits in the Ohio River. The company uses churn drills to prospect bars that outcrop above water level. It owns two islands in the river that have been prospected in this manner. For underwater bars a sounding rod is used in the hands of the operator from a small boat. By this means, gravel beds are "felt" or "sounded" beneath the river bed of fine silt. When gravel is located by sounding, the ladder dredge is moved to the spot and exploration continued by actual digging.

I. C. 6537

The East Texas Gravel Co.'s deposits are in old flood plains of the Trinity River. The material is typically fluvial, showing well-rounded, smooth-surfaced limestone gravel and angular siliceous sand. Prospecting in this region is largely confined to test pits and churn or bore holes. Many of these are negative or blanks. This illustrates the expense attendant on examining erratic deposits, or deposits which change in character within short distances. Flood plains follow the course of present or ancient streams. In the latter case later erosion has destroyed surface evidence of their presence except what remains in the topography resulting from terraces. Test pits are dug by hand 3 by 5 feet in sections where the walls will stand. When loose a cylindrical steel curbing 3 feet in diameter is used to protect the men. The small orange-peel bucket and the churn bailer are also used, the former above the permanent water line and the latter below the water line. The bailer itself is 8 inches in diameter fitted with a flap valve and a 3-pronged cutting edge. When operated by hand it should not be more than 2 feet long. This will require 8 men working 6 at a time. This type of bailer is also used on a cable-type well drill to take the place of the drill bit and rods. With the latter equipment 2 men can drill 70 to 80 feet in 10 hours.

The author cites the use of a rotary boring machine mounted on a small gasoline tractor which successfully bores a hole 16 inches in diameter in clay to a depth of 18 feet. This machine will bore at the rate of from 1 to 5 feet per minute in such material but did not prove successful in cutting gravel because of pebbles caving from the sides of the hole.

I. C. 6580

At Oxford, Michigan, the Ward Sand & Gravel Co. are operating in what is probably the remains of a ground moraine, the upper portion of which has been reworked by fluvioglacial waters which have removed most of the clay. Clay hills to the north are probably the remains of old terminal or recessional moraines from which glacial waters removed portions and deposited them on the ground moraine. This is indicated by the gradation from coarse gravel near these clay hills to fine sand on the southern side of the deposit. Below the permanent water line occasional beds of clay are found in the deposit showing little erosion by running water.

Prospecting and exploration was done by sinking test pits from 10 to 40 feet or to water level. Timber was used in some test holes in the form of 2-inch planks laid as cribbing. A churn drill was used to explore below the water level. The author expresses his opinion that "it is impossible to form an exact estimate of the value of the deposit until after it has been put in production."

Since this is probably a ground moraine topped by a shallow outwash plain, it is not surprising that analysis of test results might be puzzling. A knowledge of the geology would be a great help as a basis from which to interpret test-hole data, and with such knowledge a more comprehensive interpretation might be possible. Ground moraines, formed as they are beneath the ice, are heterogenous mixtures of material which present difficulties in analysis to the most experienced samplers.

I. C. 6581

The deposit at Clowdy, Tex., operated by the Dallas Washed & Screened Gravel Co. lies about $1\frac{1}{2}$ miles from the present channel of the Trinity River.

Composed of material ranging from fine, angular siliceous sand to well-rounded limestone pebbles up to 3 inches in diameter, it is typical of fluvial material which has traveled a comparatively short distance. This particular deposit is probably the site of a previous channel of the river, as it cut its way across the coastal plain. The material deposited came from limestone ledges in the higher ground to the north and west. The Trinity River is now a silt-bearing stream and has not carried gravel for a considerable time. This accounts for the heavy clay mantle above the gravel at Clowdy. This is then a river-bed deposit formed in the coastal plain by a meandering river and later covered by silt or clay. When the river left this channel it frequently flooded and overran its banks, leaving the clay mantle as a flood-plain deposit.

In prospecting, this company used auger holes spaced at 300-foot intervals. These were sunk to water level. It will be noted that the overburden was clay and the gravel loose and without boulders. This is most favorable to auger prospecting. These holes were drilled by hand at a cost of 15 cents per foot. They were used, however, only to outline the deposit and to determine the depth of overburden.

Next, test pits were sunk on 600-foot intervals to determine the character and thickness of the deposits. From the pits it was found that the permanent water level was from 4 to 8 feet above the bottom of the gravel, with the same variation below the top of the gravel.

An average of 7 feet of overburden was also disclosed. The shallow water and comparative thin gravel stratum (12 feet) indicated that drag lines would prove more economical equipment than dredges.

Some test pits were sunk by hand at a cost of \$1.50 per foot and others by a 1-yard caterpillar crane at a cost of \$1 per foot.

An attempt to use a 6-inch casing with a 5-inch bailer for testing below water level was unsuccessful where the material contained a considerable proportion of pebbles $1\frac{1}{2}$ inch or larger in diameter, because of the slow progress incident to pebbles binding between bailer and casing. Possibly if the bailer had been smaller in diameter, better progress would have been made.

The report describes the methods employed in analyzing tests as follows:

After the areas and thicknesses of the gravel deposits were determined, the volume of gravel was calculated and converted into tonnage by assuming a weight of 3,000 pounds per cubic yard. Screen analyses of the material from various test holes were then made and the average percentage of sand and gravel that should be recovered from the property was estimated.

Two methods were used to obtain samples for screen analysis. When test holes were dug with the dragline, the overburden was cast on one side of the hole and the gravel on the opposite side; then an average sample was selected and shoveled into a sack. When test holes were dug by hand, samples were obtained above the water line by removing two shovelfuls of material from the side of the test hole. These samples were taken at regular depth intervals of 3 feet and all samples from a hole were mixed to obtain the average of the material above the water line. Samples from below the water line were removed from the center of the holes at the same depth intervals. The information obtained from these tests has been valuable in coordinating mining with market requirements due to the variance in both the quality and size of material in the deposits and the size and grading of material required by customers.

Tests on all of the Trinity River gravel deposits have shown that the thickness of the strata, size and quality of material, and even the color of the gravel and sand change within short distances. The deposits are irregular in shape and change from gravel to sand, clay, or loam, in some instances in a distance of 10 feet or less.

Because of the erratic nature of this deposit, it would appear that at least occasional tests would be needed at shorter intervals than the 300 feet indicated.

I. C. 6582

The J. K. Davison & Bro. Co. operate ladder-type dredges in the Allegheny River near Pittsburgh, Pa. The deposits are river bars composed largely of large pebbles and boulders brought down from Canada in a glacial stream of torrential proportions. The sands are siliceous and angular while the pebbles are well rounded. The absence of fine sand and silt except on top of the deposits and the low content of coarse sand indicate the fluvioglacial source. Recently finer sands and silts have been brought down from the erosion of sedimentary rock above and dropped on the original deposits, but these are thin and of minor importance. The reader is referred to U. S. Geological Survey Bulletin 430, pages 388 to 399, by C. W. Shaw, for a more detailed geologic description of these deposits.

The company has never spent much time in systematic prospecting. Prior to the erection of navigation dams in the river the bars were exposed to visual examination. The author admits, however, that mental notes of the location of these bars has not always proved accurate. Prospecting and exploration is confined to actual digging by the dredge.

I. C. 6592

The operations of the Seaboard Sand & Gravel Co. are confined to the moraine deposits on the north side of Long Island. These deposits are described by Nevin²⁰ as a terminal moraine left by an early ice sheet originating in Labrador. It is supposed that the southern half of the island is a second moraine left by a succeeding ice advance.

The author described the deposits as follows:

The surficial deposits of Long Island are of glacial origin. They are composed almost entirely of sand and gravel, particularly along the north shore, but there are occasional beds of clay and boulders. The clay varies in quantity and occurs at almost any depth in the deposits. The boulders, however, are more systematic in their occurrence. In every case in the writer's experience, they are found at the surface, or within 8 or 10 feet of it. The overburden on Long Island consists of top soil, which never exceeds a depth of 2 feet and is not more than 4 or 5 inches thick on the property now being worked. Here the sand and gravel occur in well-defined strata, which vary in thickness from a few inches to several feet. These strata are more clearly defined near the surface where the gravel content is much heavier than deeper in the bed. With depth the layers disappear and the material seems to be largely sand with occasional pebbles in it. No clay has been encountered in the bank now being worked.

From the author's observation of occasional accumulations of clay and boulders within the sand and gravel, one infers the moraine origin. He also states, however, that the sand and gravel occur in clearly defined strata near the surface. Since Nevin finds evidence of two moraine deposits, of which that on the north shore of the island is the older, it is probable that this deposit was subjected to considerable reworking by glacial waters and possibly wave action. This would account for the gradation near the surface with untouched clay accumulations below in the original moraine.

Prospecting this deposit was simple, as it occurs on a promontory exposed on three sides. Shallow test pits were dug, however, to confirm the visual inspection.

I. C. 6607

The deposit exploited by the Consolidated Rock Products Co., at Durbin, Calif., is a typical alluvial fan deposited by the San Gabriel River. There are no distinct layers of sand or gravel, but the material ranges coarser in size as the river canyon is approached. The permanent water level was determined at 110 feet below the surface. Drill-hole logs indicate a depth of deposit of over 300 feet.

Previous operators had thoroughly prospected the property but to confirm their results the company dug two 4 by 4 foot test pits to water level at a cost of \$4 per foot. The material dug from these pits was tested and the information used to design a plant to handle the several gradations indicated.

The pits were timbered in 4-foot square-sets, and the material excavated between each set was piled separately on the surface. Five-hundred-pound samples were taken from each pile and first screened through a 3/8-inch screen to separate the sand from the gravel. The gravel was then put over a screen with 3-inch round perforations. The undersize from this screen represented gravel and the oversize that proportion that would require crushing. The

20 - Nevin, Chas. M., The Sand and Gravel Resources of New York: New York State Museum, Bull. 282, 1929, pp. 124-125.

gravel sample was then separated in the various commercial sizes to determine their ratio of occurrence.

SUMMARY

In this report the author has endeavored to point out the necessity for proper prospecting and exploration of a sand and gravel deposit before exploitation begins, the reasons for such necessity, the information to be gained, and the application of such information in valuing the material.

Typical examples of methods employed by operating companies have been cited and costs given when available.

It is hoped that the information contained herein will be of assistance and guidance to operators contemplating the opening of new deposits and that it will induce them to ascertain thoroughly all available facts before investing capital, in order that such investment be founded on facts rather than hopes. In this way waste may be prevented and unwise exploitation avoided.

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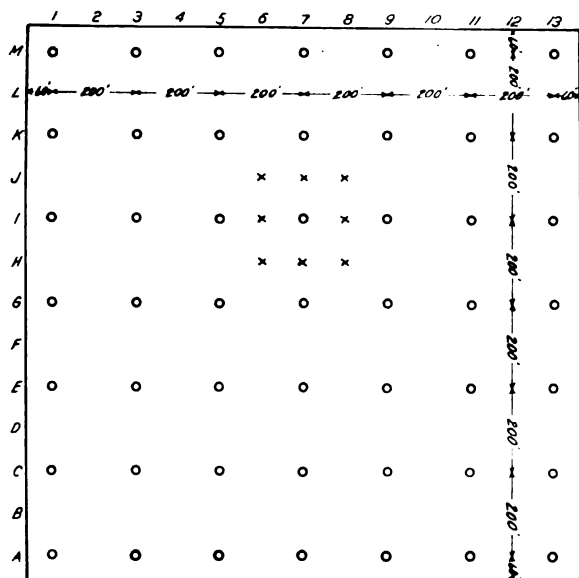


Figure 10.- Drill-hole plan

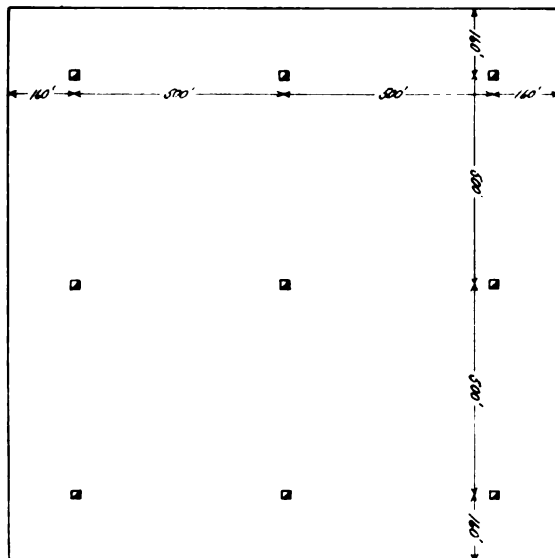


Figure 11.- Test-pit plan

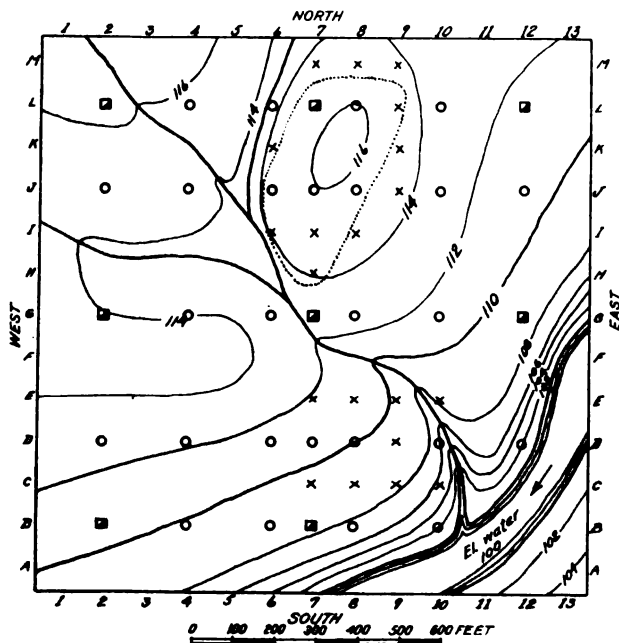


Figure 12.- Contour map

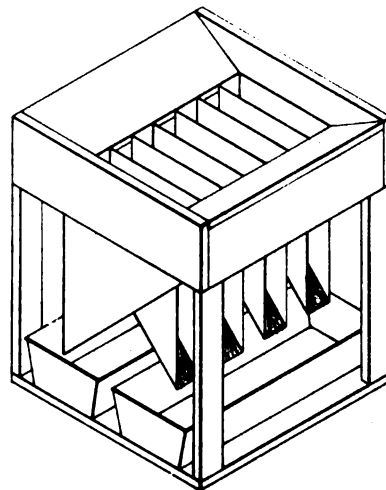


Figure 13.- Sample splitter